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COMING MEETINGS

Spring Convention, Pittsburgh, April 24-26

Annual Convention, Swampscott, Mass., June 25-29

Pacific Coast Convention, Del Monte, California, September 25-28

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American Physical Society, Washington, D. C., April 21

American Society of Mechanical Engineers, Montreal, May 28-31

American Society for Testing Materials, Annual Meeting, Atlantic City, N. J., June 25-30

National Electric Light Association, New York, June 4-8

Pacific Coast Electrical Association, San Francisco, June 19-22

Society of Industrial Engineers, Cincinnati, April 18-20

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Vol. XLII MARCH, 1923 Number 3

TABLE OF CONTENTS

Papers, Discussions, Reports, Etc.

Institute and Related Activities

Current Electrical Articles Published by Other Societies

Journal of the American Welding Society, January, 1923

Developments in Arc Welding, by O. H. Eschholz.

Production Welding in the Sheet Metal Shop by J. W. Owens

Electrodes, by J. Caldwell.

Association of Iron and Steel Electrical Engineers, January, 1923

Prosperity and Industry, by Wray Dudley.

Transactions of the Illuminating Engineering Society, February, 1923

The Cost of Daylight, by M. Luckiesh and L. D. Holladay.

Lighting for Motion Picture Studios, by F. S. Mills.

Flicker Photometry, by C. E. Ferree and Gertrude Rand.

The Measurement of Power in Polyphase Circuits*

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Review of the Subject.—*The object of this paper is to point out that the existing methods of measuring power when applied to unbalanced three-phase systems are not equitable for symmetrical polyphase machinery. On the other hand, unsymmetrical loads on polyphase systems are not sufficiently penalized for the trouble which they create in the system.*

It is first of all shown that a symmetrical generator cannot deliver power except through the balanced components of current. The unbalanced currents are capable of resolution into two balanced systems of currents, one of which is of the same phase sequence as the generator e. m. f., and the other component is of reversed or negative phase sequence. The generator cannot deliver power through the medium of this latter component of the currents, because the instantaneous product of the generated voltage and these currents in the three phases is always zero. However, the volt-ampere product per phase is of great significance, because it is a measure of the effect of the current unbalance on the system.

The generator therefore delivers power only through the medium of the positive phase sequence currents. Any power that appears in the system through the negative phase sequence currents is positive phase sequence power which has been supplied by the generator and degraded through unbalanced loads and fed back to the system in the form of negative phase sequence power. This power is always additional loss in all rotating machines on the system, and with the present method of charging, the consumer having symmetrical machines is charged with this additional power, which serves him no useful purpose but reduces the output of his machine and decreases his load power factor.

In the paper it is proposed that the positive phase sequence power output only be measured, and the power charges be made on the basis of this measurement. It is further proposed that the unbalanced k-va., which is the product of the positive sequence voltage and the negative sequence current be measured either by means of a negative sequence ammeter, indicating or recording, or a k-va. meter, and a charge made for the amount of unbalance. The user of symmetrical polyphase rotating machinery should then be given a lower rate, based on the estimated cost of unbalance, and the consumer having unbalanced loads should be charged directly for the amount of unbalance he creates, or else should have his positive phase sequence power rate increased, based upon the estimated cost of unbalance.

It is pointed out that the unbalanced kv-a. is a factor of the same order of importance as reactive kv-a. and in any system subject to unbalanced conditions this factor should be considered and the unbalanced factor, as well as the power factor, should be measured. The unbalanced factor is the ratio of the negative phase sequence kv-a. and the positive phase sequence kv-a., the former being obtained by taking the product of the positive phase sequence voltage and the negative phase sequence current.

Devices for measuring these quantities are being developed and the outfit for making these measurements will be no more complicated than the present existing measurement devices. In fact the tendency is towards greater simplicity.

In presenting this subject the author has no intention of suggesting how rates should be made, but merely wishes to point out what factors enter into the question of equitable rates when the polyphase system is subject to unbalance.

Generators

FOR the purpose of this discussion, it will be sufficient to consider symmetrically wound machines. Such machines when excited by a direct-current machine, give balanced three-phase voltages at their terminals of sine wave form. If currents are supplied from these terminals to a symmetrical load, they will be in balanced three-phase relation to one another, and the sequence of the maxima of the current waves will be the same as that of the generated e. m. f. waves. Generators are usually built with the field the rotating member; to avoid confusion we shall refer to this member as the rotor and the rotor field will in general be the main field of the machine, although as we shall see later, the main field is, in reality, a field set up by the resultant of the m.m. fs. of both stator and rotor.

A symmetrical system of currents flowing in the stator winding produces a resultant synchronously rotating m. m. f. which in the case of balanced currents having the same sequence of phases as the generated e. m. fs. will rotate in the same sense as the main field, and its phase position with respect to the main field will depend upon the time phase of current with respect to the e. m. f. Where the relation between m. m. f. and field in linear, the former may be resolved into two components at right angles with each other, and the field that would be produced by these m. m. fs. may be compounded with the field produced by the exciter currents in the stator to give the actual field of the machine under load. Since the e. m. fs. produced by the components will be proportional to them, we may consider these components in terms of the e. m. fs. they produce in the stator winding and compound these instead. Thus, in each phase an e. m. f. will be produced by the resultant magnetomotive force due to the symmetrical currents flowing in the stator windings and will lead it in time phase by one quarter of a cycle. In addition to this e. m. f., there will be a resistance drop due to the current in its windings. A complete theoretical discussion of these problems is given in the appendix. It is shown there that if the resistance drop which is negligible is ignored, the increase in exciting current required to maintain a given e. m. f. is proportional to the wattless current, and the phase angle of the rotor and armature adjust themselves, so that there is equilibrium of induced voltages. In other words, the presence of wattless lagging current in the winding necessitates a proportional increase in the exciting current. This entails larger conductors in the exciting winding and larger parts for the complete machine. The effect of saturation is not so important as might be supposed; for since the field itself does not

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change in value during a cycle, the value of the average mutual and self inductance will not be affected during a cycle, but will depend upon the average degree of saturation present. In most machines this does not vary much from no-load to full-load on account of the long air gaps.

Let us suppose the generator to be provided with a winding on the rotor of similar character to the stator winding, but short-circuited on itself. It will be quite obvious that the various component fields discussed above, since they are stationary with regard to the rotor, will have no inductive influence on this winding and that, therefore, so long as the machine is rotating at uniform speed, and the currents in the winding of the stator are symmetrical three-phase of the same sequence as the terminal e. m. fs., no current will flow in this winding. Let us now consider the effect of a system of balanced three-phase current, the sequence of whose maxima is opposite to that of the generated e. m. fs., that is to say, the maxima of the currents in phase *A. B. C.* instead of following in time the order *A* leading *B* and *B* leading *C*, will instead follow the order *C* leading *B* and *B* leading *A*. It will be evident that the sequence of these currents will correspond with the normal sequence of currents for the same machine with the direction of rotation reversed, consequently following the same general reasoning for the case of normal sequence given above, this system of currents will set up a m. m. f. rotating synchronously in the opposite direction to the m. m. f. of the exciting current of the rotor. This m. m. f. will, therefore, rotate relatively to the distributed winding on the rotor at double synchronous speed and the field it will tend to produce will set up double frequency-balanced polyphase currents, which will in turn set up a m. m. f. opposing that due to the stator currents.

The field actually produced will be the resultant of these two opposing m. m. fs., and will be such as to produce e. m. fs. of sufficient value to overcome the impedance of the rotor winding due to its resistance and leakage reactances. We have here an action similar to that of a short-circuited transformer, the difference being that there is in addition a tranformation of frequency that is always accompanied by a transformation of mechanical power into electrical power. In this particular case, the transformation of mechanical power into electrical is such that one-half the secondary losses are directly supplied through rotation by the prime mover. The e. m. f. at the generator terminals required to force this current through the stator windings will be determined by an impedance which will be similar to the short-circuited impedance of a transformer. Similarly, the relation between the double-frequency rotor current and the stator current will be similar to that between the secondary and primary currents of short-circuited transformers. For practical purposes, we may say that the ampere-turns of stator and rotor winding will be equal. These relations are independent of the actions accompanying the flow of balanced currents of normal frequency in the windings.

It will now be evident that the presence of current of opposite phase sequence in the generator e. m. f. requires something in the generator which was not necessary before, that is, damper capacity, and this is a further requirement in addition to the additional capacity required in the stator winding as a result of the current.

The product of the negative phase sequence current and the normal terminal voltage is a measure of the amount of phase conversion taking place in the generator and the presence of the negative phase sequence current requires this phase converting capacity in the machine. The mean heating in the stator will be proportional to the sum of the squares of the positive phase sequence current and the negative phase sequence current; and the heating in the rotor will be proportional to the sum of the squares of the exciting current and the double-frequency current if they have a common winding.

It has been shown elsewhere and the solution has been repeated in the appendix that the operation of a generator depends upon two fundamental inpedances, namely, the impedance to the normal balanced current or positive phase sequence impedance, and the impedance to the negative phase sequence current, the action of which we have just discussed; this latter is the negative phase sequence impedance.

In this discussion we are leaving entirely out of consideration currents flowing through the winding by way of the neutral of the three-phase winding. These currents while important in questions of inductive interference are of little importance in commercial power circuits. It seems hardly necessary to say that a solution of any circuit condition may be obtained without the use of positive and negative sequence currents and impedances by using self and mutual impedances. These impedances are, however, difficult to evaluate and are not the natural constants of the machine.

A discussion of the equations of a generator using self and mutual impedances and the derivation of their relation to the positive and negative phase sequence impedance will be found in the appendix. This method of solution might be regarded as the single-phase method of treating a polyphase problem, each phase being considered as a single-phase branch circuit related to the other circuits through mutual impedance.

In the symmetrical coordinate method, the symmetrical polyphase component system are the units, and these have definite impedances and are independent of each other in a symmetrical machine. This method, therefore, leads to considerable simplification. It is interesting to note that a similar relation holds between the phase impedances and the positive and negative sequence impedance, as exists

between the phase currents and the positive and negative sequence components of current.

We are not concerned, however, with the mere solution of the three-phase circuit, but what we desire is a measure of the requirements of the machine.

(1) How much true power it must carry—kw. capacity.

(2) How much reactive power it must supply—exciter capacity, field copper, additional stator copper.

(3) How much unbalanced kv-a. it must supply—its phase-converter capacity—damper windings on rotor—additional copper on stator.

The first two requirements are well known, the first being determined by the demand for power current or active component of current, the second being determined by the demand for magnetic energy which is furnished by the reactive component of current. The third requirement is determined by the magnitude of current unbalance, and is measured by a balanced system of currents, the sequence of the maxima of whose phases is the reverse of that of the generated voltage.

If we take I_1 for the total current due to the first two, then if $I_p\, I_Q$ be the two components of power current and wattless current respectively, $I_1^2 = I_p^2 + I_Q^2$. If I_2 be the third current, which measures the magnitude of the unbalanced flow, the total average heating in the stator alone will be determined by $I_1^2 + I_2^2 = I_p^2 + I_Q^2 + I_2^2$, so that in its relation to the generator capacity, I_2^2 is a factor of the same order as I_Q^2, and the three quantities as regards the average heating are independent of one another, and the necessity for supplying I_2 calls for additional copper in the stator winding as well as the addition of a suitable damper winding. To sum up: The character of a generator is such that it has three functions:

(a) To deliver true or active power.

(b) To deliver reactive power or supply magnetic energy.

(c) To maintain balance at its terminals (phase converter capacity.)

The quantities that are measures of these three characteristics combine as far as average total heating is concerned as if they were three vectors in space mutually at right angles to one another.

In the preceding paragraphs, we have concerned ourselves only with the average heating, due to the presence of unbalance currents. We have shown that a machine subjected to such operating condition must have damper capacity and additional copper in the stator; but this is not the whole story, the effect of unbalance is to cause unequal dissipation of energy in the three phases, as a result any phase may have to withstand a loss several times the average loss according to the average loss expression given in one of the preceding paragraphs. Since the phase of the negative phase sequence component current is not definitely fixed, any one of the three phases may have to stand this high loss. In a single-phase machine, the unbalance is definite and may be provided for, but in a three-phase machine, each winding must be designed for the maximum possible loss it may incur under unbalanced loads.

It appears to be a reasonable deduction that the simplest system and the most fundamental one in considering a rotating machine, is one in which the reactions in the magnetic circuit will appear in terms of fields of the same character as that set up by the rotor. We see that balanced currents flowing in the stator will set up a field of this character which may be combined simply with similar fields set up by other balanced systems of currents. The balanced systems of currents in the stator setting up these component fields will differ from one another in magnitude, phase-sequence and frequency. Any particular component fields may be the resultant of two balanced systems of current, one of which flows in the stator winding and the other in the rotor. A balanced system of currents which produces a m. m. f. rotating in the same direction as the main field is termed a positive phase-sequence system. A system of balanced currents flowing in the stator producing a field rotating in the opposite sense is termed negative phase sequence. It is convenient to refer all the quantities to one phase "*A*" which is termed the principal phase.

In dealing with the generator in these terms, we are considering the field as resolved into component fields of exactly the same character as that set up in the field magnetic circuit by the exciter. In the complete theory the field may be compounded of a number of fields of different numbers of poles rotating at different multiples or submultiples of the speed of the main field. Rotating positively or negatively each field is associated with a symmetrical system of currents in both rotor and stator, each having a definite frequency depending on the speed of rotation of the field and a definite phase sequence depending on the direction of rotation.

The instantaneous value of the field set up by a symmetrical system of currents of other than sine wave form in a symmetrically wound generator may be expressed in the form of a Fourier series consisting of only odd harmonics of the fundamental, the electric angle for a complete pole pitch being 2π. In the three-phase symmetrical generator, there may be present in the field form, due to the symmetrical currents, the 5th, 7th, 11th, 13th, etc., harmonics of which the 5th, 11th, 17th, etc. will be fields rotating in the negative direction while the 7th, 13th, 19th will be positively rotating fields.[1] On account of the counter m. m. fs.

1. The reason of this may be explained very simply as follows: If we take the wave form of say phase A and displace it through the angle $\frac{2\pi}{3}$ we obtain the wave form of phase B for a symmetrical machine. For the rth harmonic which has $1/r$th the wave length, this displacement corresponds to the harmonic

due to currents set up in the damper winding and in the pole faces, these harmonic fields are largely damped out. The harmonic fields due to the flow of symmetrical positive phase-sequence currents of fundamental frequency do not produce harmonic e. m. fs. in the stator, but the e. m. fs. produced are all of fundamental frequency and of symmetrical positive phase sequence. The field forms so produced are of the nature of submultiple rotating fields, having numbers of poles related to the main poles in the inverse ratio of the relative rotational speeds. Their values are small, due to the counter reactions set up by the induced currents in the rotor.

The fields set up by the flow of negative sequence current of fundamental frequency in the stator are of similar character, but the direction of rotation is reversed, consequently, all these fields are opposed by those of the currents set up in the damper windings. All the e. m. f. set up in the stator is used up in overcoming the resistance and the internal reactance of its windings and in addition a certain amount of mechanical power is required to produce a portion of this e. m. f. which is dissipated in the form of $I^2 R$ in the rotor windings. The e. m. fs. set up in the stator are all dissipative and reactive e. m. fs.

A symmetrical rotating machine driven below synchronous speed is incapable of delivering power when excited in the primary alone; an additional exciting agent in the secondary circuit is required. Any mechanical power necessary to drive such a machine is used up in heat losses in the windings. The above includes machines driven in a negative direction at any

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angle $= \frac{2 r \pi}{3}$. If r is a multiple of 3, we see that the angle $-\frac{2 r \pi}{3}$ is always a multiple of 2π or a complete electrical revolution, so that in a three-phase machine, all harmonics which are multiples of 3 give voltages in phases A B C in phase with one another. The two groups of numbers $(6 n - 1)$ obtained by giving n all integral values from 1 to infinity give all the odd integers from 5 to infinity, except the multiples of 3. If we take r equal to $(6 n - 1)$ this group of harmonics will be displaced by the angle $- 4 n \pi + \frac{2 \pi}{3}$ or what is the same thing by the angle $\frac{2 \pi}{3}$ that is to say phase B will be advanced by this angle; similarly if r is taken equal to $(6 n + 1)$ the angular displacement for the harmonic will be $-\frac{2 \pi}{3}$, that is, this group of harmonics will be displaced in phase B by the angle $-\frac{2 \pi}{3}$. Hence the first group will be positive phase sequence, while the second will be negative phase sequence. In $(6 n - 1)$ giving all integral values, we obtain the harmonic group 5, 11, 17, etc., and similarly, the group $(6 n + 1)$ gives the harmonics 7, 13, 19, etc.

speed. There is an apparent exception to this in the case of standard generators; due to the saliency of the poles, they are capable of delivering a certain amount of power when excited from the primary. This characteristic is the result of the variation of inductance of the stator winding with varying position of the rotor, and may be regarded as a form of dissymmetry. The amount of power a machine is capable of delivering in this way is a fixed fraction of the total exciting kv-a. Steam turbine generators have very little of this characteristic.

The generator relative to the negative phase-sequence current is being driven backwards at synchronous speed, and, therefore, as we have shown, if it is a symmetrical machine, it cannot deliver any useful work at its terminals through the medium of the negative phase-sequence currents. The mechanical power at the shaft, due to the negative phase-sequence currents is completely used up in losses in the damper windings. In short, a generator cannot deliver useful power at its terminals, except through the system of e. m. fs. set up through its main field excitation. It will now be apparent that a symmetrical generator cannot deliver any other than positive phase-sequence power. All the negative phase-sequence current flowing therein represents losses; the flow of these currents requires also the application of a certain amount of mechanical torque at the driving shaft which must be supplied from the true source of power which in the case of a generator is the prime-mover.

One special form of generator should be mentioned, in which the field windings have high external reactance and the field is thoroughly laminated and is not provided with damper windings. In such a machine the impedance to negative phase-sequence current is the same as that to positive phase-sequence current. Such a machine delivering a single-phase load will have a pulsating field. Moreover, the harmonics due to the field form will not be damped out as in the machine provided with damper winding. The unbalance in voltages due to unbalanced load in such a machine will be very marked.

It is possible that a generator may give perfectly balanced voltages at no load and will be inherently unbalanced under load. The fact that a symmetrical generator cannot deliver power through the negative phase-sequence currents affords a simple check to determine whether an unbalance is wholly due to external sources or is partly inherent in the generator. The total negative sequence power output may be measured, and if it is negative, the unbalance is due mainly to external conditions; if it is positive, a great part of the unbalance is inherent.

THREE-PHASE INDUCTION MOTORS: SYNCHRONOUS MOTORS: ROTARY CONVERTERS:

The action of polyphase motors is quite similar to that of polyphase generators. Thus, if the machine is

an induction motor, at no load, the rotor, since it is rotating at near synchronous speed, is traveling at approximately the same angular velocity as the field set up by its primary currents; there is, therefore, practically no current set up in the secondary winding. The effect is similar to that in an open-circuited transformer. As a load is thrown on the motor, the speed decreases and sufficient current flows in the secondary to produce the required torque. In the case of negative phase-sequence currents in the primary, the rotor is traveling, relative to the field set up by these currents, at double synchronous speed, approximately; the effect, therefore, is similar to that in a short-circuited transformer. For a slight unbalance of the impressed voltage, a relatively larger unbalanced current will, therefore, flow. If the negative sequence input is measured, it will always be positive if the motor is tending to maintain a balance. If it should read negative, the motor is unsymmetrical, and is causing unbalance. The above analysis applies equally well in the case of synchronous motors. In the case of rotary converters, the effects of unbalance may be quite serious for the negative phase-sequence current is not commutated, but circulates in the winding and produces secondary double-frequency currents. Both primary and secondary currents may be quite large, and since the former is not compensated by the flow of direct current, it has its full heating effect in the windings. Moreover, the negative phase-sequence current in the primary sets up a double-frequency voltage between commutator segments, which increases the tendency to flash over. A certain amount of double-frequency current flows through the brushes into the d-c. system, heating the brushes and causing inductive disturbances.

In the measurement of power supplied to a symmetrical motor, we are chiefly concerned with its operation considered with reference to a balanced positive phase-sequency system which is the standard polyphase system of reference in the same way that the sine wave is the standard wave form of current and e. m. f. As pointed out in a preceding paragraph, in a symmetrical motor, the total power input which is the sum of the positive and negative sequence power, is greater than the positive phase-sequence power input and the difference constitutes loss in the motor, due to the unbalance. But this is not the only loss due to the unbalance; there is a counter torque required to assist in driving the double-frequency current through the secondary windings, and this is supplied by the positive phase-sequence power which is also increased as a result of the unbalance; the increase is, however, very small, being approximately equal to one-half the secondary loss due to the double-frequency current flowing therein, and it may practically be ignored.

It will be apparent from the above statement that the existing methods of measuring power input to motors and rotary converters are not quite equitable and penalize the machines that assist in balancing the system while it favors those which inherently have characteristics that increase unbalance.

The simplest procedure to obtain the input of power to polyphase motors is to ignore the small additional loss due to the back torque set up by the negative phase-sequence currents in the motor, and to take the positive phase-sequence power and kv-a. or power factor as a measure of the performance of the machine. This method is a great deal more accurate than the present method of measuring the performance of the machine by the total power input and the effective power factor.

The product of negative phase-sequence current and positive phase-sequence volts, is a measure of the phase balancing or unbalancing effect of the motor on the circuit. When it is known that the motor is symmetrical, this will always measure the balancing effect of the motor on the system. When there is doubt as to the symmetry of the motor, the question as to whether its operation is favorable or detrimental to the balance of the circuit may be answered by obtaining negative sequence power input. If the value is positive, the operation is favorable; if it is negative, the operation is detrimental. There are certain cases where these criteria fail, but the number of cases in which it will be necessary to apply the test is small, and the number of cases in which the test fails is an unimportant figure.

Single Phase Motors

Considered from the point of view of symmetrical coordinates, single-phase motors are only a special case of three-phase motor unbalanced operation. The positive phase-sequence current and the negative phase-sequence currents are equal in magnitude; the unbalancing effect of such a motor is, therefore, quite definite and is equal to its positive phase-sequence kv-a.

It would appear reasonable to charge a consumer, using single-phase motor, on the basis of this unbalanced kv-a. whether other consumers using similar machines, when operating simultaneous with his, are connected, to jointly produce a balance or not. The cost of single-phase service on polyphase systems should be based on the cost of unbalance, compiled from the previous year.

This method of charging could be extended to all single-phase power loads, and would be equitable except in the case of consumers having mixed loads, who should be encouraged to balance up the single-phase portion of their loads as far as practicable. It should be remembered, however, that single-phase loads even when perfectly balanced are inferior to balanced polyphase rotating loads, because the latter have high inherent balancing characteristics which the single-phase balanced loads do not have. That is to say, the admittance to negative phase-sequence current for a balanced single-phase load is the same as its admittance to positive phase-sequence current, whereas in the case

of a polyphase synchronous or induction motor or rotating converter carrying the same load, admittance to negative phase-sequence current may be many times that to positive phase-sequence currents.

Single-Phase Lighting

The same comments apply to this type of load as to single-phase motors, except that the power factor being near unity, the lighting load becomes less objectionable from this standpoint. When it is possible to balance the loads on all phases, it should be done by the consumer as closely as practicable, and he should be charged on the basis of the polyphase power consumed and the unbalance he creates. At the present stage, it will be sufficient to charge him for his unbalanced kv-a. without considering whether he is helping or hindering the balance. This charge may be considered the penalty attached to single-phase service, which is reduced in proportion to the care with which the consumer arranges his circuits. This method of charging holds equally well for all single-phase loads where they can be arranged to give good approximate balance.

Three-Phase Furnaces

The three-phase furnaces may be balanced by introducing a properly designed control. With proper control, it should be balanced both as to current and e. m. f. between neutral and terminals. Under these conditions of balance such harmonics of current as occur will be a minimum. A practical method of obtaining balance, is with the use of a series phase balancer which will be small as compared with the output of the machine. This should be combined with a voltage regulator to control the depth of the electrodes; in this way perfect balance as to the current as well as voltage may be obtained. Furnace loads when balanced have no inherent balancing capacity whatever, and therefore all unbalanced kv-a. should be charged for. In addition if the wave form of current is very much distorted, some account should be taken of this distortion when the operating conditions warrant it.

Equitable System of Rates Based on Sequence Measurements

The positive-phase sequence power delivered to a load may be measured by a single-element wattmeter with the proper form of network constraint which can be incorporated in the meter. It has been pointed out that this power is the only power that a generating station is capable of delivering. The total power delivered measured at the terminals of a symmetrical generator which carries an unbalanced load is always less than the positive phase-sequence power. The difference is absorbed by the generator in the form of losses. In the case of a load causing unbalance, the positive phase-sequence power input will always include the negative phase-sequence power delivered to the system by the load as a result of the unbalance. Balanced polyphase loads, such as motors and balanced polyphase networks in general, do not contribute to the unbalance, but assist in maintaining balance. They absorb negative phase-sequence power, but do not transform positive phase-sequence power into negative phase-sequence power. Their operation as motors has nothing to do with their phase-balancing characteristics and is dependent solely on the positive phase-sequence power taken. There is a certain amount of positive phase-sequence power, so small that it may be neglected in the motor power, absorbed by reason of the balancing effect which is dissipated in the secondary windings as $I^2 R$ loss. The motor is performing an important service as a phase balancer for which, with the present method of charging, it is penalized. If only the positive phase-sequence power delivered is measured and charged for, this penalty will be removed and placed, where it should be placed, on the unbalanced loads on the system. The consumer who uses polyphase motors should get a polyphase rate somewhat lower than that for other kinds of polyphase load depending upon the estimated cost of unbalancing.

In the case of the consumer having a mixed load, if his single-phase load is of sufficient importance, it may be metered separately. If it is small as compared with the polyphase motor load, it may be connected so as to produce a minimum unbalance and the charge should be based on the positive phase-sequence meter reading and a rate obtained by taking the weighted average of the polyphase rate for single-phase balanced networks and that for polyphase motors, based on the respective value of the wired single-phase and polyphase loads.

In the case of single-phase loads connected so as to minimize unbalance, the power charges should be made on the basis of the positive phase-sequence power. A charge should also be made for negative phase-sequence kv-a. obtained by means of a recording negative phase-sequence current device, in the same manner as reactive power is charged for, the cost of unbalance being computed from previous results.

To sum up: Positive phase-sequence power is the only commodity manufactured by the power plant; phase balance is a service to which all consumers using polyphase motors contribute and with which users of single-phase devices interfere. Users of balanced polyphase power other than motors should pay for this service in the regular polyphase rates. Users of single-phase devices should pay over and above the regular polyphase rate depending upon the amount of unbalanced current they create. Users of polyphase motors should obtain a lower polyphase rate, based on the average amount of service they contribute to the maintaining of balance.

The meters required for assigning the proper charges are as simple or simpler than those used at the present time for polyphase power measurements and the results should prove more satisfactory and equitable all round and are based on correct theoretical grounds.

Characteristics of Transmission and Distribution Systems Required to Maintain Balanced Polyphase Service

It is essential to the maintenance of good balanced polyphase service that all banks of transformers should be symmetrically grouped that all transformers in one bank shall have the same performance and characteristics. It was not unusual in the past to find rotary converters connected to polyphase systems through a bank of open delta-connected transformers; such practises should not be tolerated except for short intervals while starting or under emergency conditions.

All feeders used to supply mixed loads should be loaded as symmetrically as possible. They should have as low impedance as possible for two reasons: (1) So that the effect of starting and stopping motors will not affect the lighting service unreasonably. (2) In order to reduce the voltage unbalance caused by any given value of unbalanced load they may incur.

Where a polyphase circuit is called upon to supply a large single-phase load, special provision should be made for the service such as heavier feeders and in many cases balancers or phase converters should be installed.

In selling power to a consumer of this kind the cost of the converter station will naturally enter into the rates charged for power, otherwise, the rates used will be the regular polyphase rates for power.

Dissymmetry in transmissions, feeders, etc. should be avoided with careful transpositions, dissymmetry in conductor arrangements may be compensated. In long transmission systems when synchronous condensers for regulating purposes are distributed over the line, they will also serve the purpose of phase balancers.

The fact that normal overloads have the characteristics of remaining balanced offers great possibilities in the way of protection on feeders selective operation and so forth. For if a loaded system is normally balanced, we may employ a positive phase-sequence relay for load control having the proper time element, and for short-circuit control, we may use the negative phase-sequence principle, and since negative phase sequence current flows only under short circuit, complete selective operation may be obtained.

There are many more applications of this principle to apparatus protection and control, too many to enumerate, that will suggest themselves to anyone who takes the trouble to study this subject.

Appendix

There appears to be a certain amount of misunderstanding in regard to the derivation of power quantities from the vector quantities used in alternating-current problems. In a recent letter, a copy of which was sent to the writer, the statement was made: "The quantity $\Sigma E_K I_K \sin \theta_K$ seems to me without physical significance, and as far as I am aware cannot be measured except when there are no harmonics present."

This quantity, however, has this physical significance, for example, in a constant voltage transmission system it is a measure of the magnetic energy that must be supplied to the system in order to maintain the voltage constant. It is also a measure of the capacity of the synchronous condensers required to supply the magnetic energy. In certain cases it would be impossible to supply more than a very limited amount of power, over a transmission line without supplying the necessary amount of this quantity which is stated to have no physical significance.

The fact that when harmonics are present the sum of these products cannot be measured with any known device is not of any great importance, as engineers are not greatly concerned with harmonic power quantities except in their elimination. It may be safely said that as far as the regulation of the lines and the supply thereto of magnetic energy is concerned these harmonic quantities have no practical significance.

Current and e. m. f. are from the point of view of linear circuits scalar quantities, but it is convenient to represent them by means of vector quantities. Similarly, power is a scalar quantity, and it is found equally convenient to represent it by means of a vector.

When the current and e. m. f. are simple harmonic quantities they are directly resolvable into two vectors rotating in opposite senses at uniform angular velocity. The power however, will not be a simple harmonic quantity but will consist of a mean term and a double-frequency term. The instantaneous power is therefore represented by two fixed vectors combined with two vectors rotating at double normal angular velocity in opposite directions. In both cases the two systems of vectors are conjugate and it is found convenient to ignore one system and represent those quantities by the positively rotating system. In the case of simple harmonic quantities such as current and e. m. f. a simple vector, rotating positively at an angular velocity, giving one complete revolution for each cycle is used. Power due to simple harmonic quantities is represented by a stationary vector which gives the mean power and a vector of the same magnitude rotating positively at double synchronous speed, or making one complete revolution for each half-cycle.

Representation of Single-Phase Power

The representation of harmonic scalar quantities by vectors is not in any sense artificial, the relations follow at once when we express the harmonic quantities in their exponential form. The ignoring of one of the two conjugate quantities naturally follows from expediency, as it simplifies matters and makes the interpretation of formulas and equations easier.

If e and i are the instantaneous values of e. m. f. and current in a circuit and $\breve{E}$ and $\breve{I}$ are the corresponding symbolic expressions for these quantities the following relations hold good:

$$e = \frac{\check{E} + \hat{E}}{\sqrt{2}} \qquad (1)$$

$$i = \frac{\check{I} + \hat{I}}{\sqrt{2}} \qquad (2)$$

where $\hat{E}$ is conjugate to $\check{E}$ and $\hat{I}$ is conjugate to $\check{I}$, and all the symbolic terms are expressed as root mean square quantities.

e and i being simple harmonic $\check{E}$ and $\check{I}$ take the form $E\, e^{jwt}\, I\, e^{jwt}$ when ω is $2\,\pi$ times the frequency.

In carrying out linear operations on i and e it is unnecessary to consider the conjugate terms $\hat{I}$ and $\hat{E}$ as the same operation on these terms yield a result which is the conjugate of that obtained by operation on $\check{I}$ and $\check{E}$. We may say therefore that i and e are fully represented by the symbolic terms $\check{I}$ and $\check{E}$, and that their actual value may be determined by either adding the conjugate term to each of these quantities and dividing by $\sqrt{2}$ or by taking the real part of these quantities multiplied by $\sqrt{2}$.

The instantaneous power delivered to the circuit is $e\,i$, and when the values of e and i are expressed in terms of $\check{E}$ and $\check{I}$ and their conjugates we obtain

$$e\,i = \frac{\check{E}\,\hat{I} + \hat{E}\,\check{I}}{2} + \frac{\check{E}\,\check{I} + \hat{E}\,\hat{I}}{2} \qquad (3)$$

e and i being both simple harmonic

$$\check{E} = E\,e^{jwt} \qquad \hat{E} = E\,e^{-jwt}$$

$$\check{I} = I\,e^{jwt} \qquad \hat{I} = I\,e^{-jwt}$$

so that the term $\dfrac{\check{E}\,\hat{I} + \hat{E}\,\check{I}}{2}$ is constant and represents the mean power. The term $\dfrac{\check{E}\,\check{I} + \hat{E}\,\hat{I}}{2}$ is a harmonically varying quantity of double normal frequency and consequently its mean value is zero.

The mean power input is defined in the usual manner by the integral

$$P = \frac{1}{2\,\pi} \int_0^{2\,\pi} e\,i\,d\,\theta$$

where θ is equal to $\omega\,t$ at any instant t. If we substitute from (3) for $e\,i$ and carry out the integration we obtain

$$P = \frac{\check{E}\,\hat{I} + \hat{E}\,\check{I}}{2} \qquad (4)$$

since the second pair of quantities in equation (3) being of double frequency becomes zero when integrated between the limits o and $2\,\pi$.*

If we have an electric system consisting of linear circuits having self-induction and mutual induction, its electromagnetic energy W is a quadratic function of the currents or $W = 1/2\,L\,i_1^2 + M_{12}\,i_1\,i_2 + 1/2\,L\,i_2^2 + \ldots$ Taking into account the dissipative forces we have

$$e_1 = R\,i_1 + \frac{d}{d\,t}\,\frac{\partial\,W}{\partial\,i_1}$$

we find that

$$1/2\,R\,i_1 \int^t i_1\,d\,t + W = 1/2\,i_1 \int^t e_1\,d\,t$$

$$\int^t e_1\,d\,t = j\,\frac{\hat{E} - \check{E}}{\omega\,\sqrt{2}} \qquad \text{for a sine wave}$$

t being measured from any convenient datum. Therefore

$$i/2 \int e_1\,d\,t = -\,j\,\frac{\check{E}\,\hat{I} - \hat{E}\,\check{I}}{4\,\omega} - j\,\frac{\check{E}\,\check{I} - \hat{E}\,\hat{I}}{4\,\omega} \qquad (5)$$

The mean value of this integral is therefore given by

$$-\,j\,\frac{\check{E}\,\hat{I} - \hat{E}\,\check{I}}{4\,\omega}$$

and this is equal to W the electromagnetic energy since the mean value of $1/2\,R\,i_1, \int^t i_1\,d\,t$ is zero. We thus have

$$W_{mean} = -\,j\,\frac{\check{E}\,\hat{I} - \hat{E}\,\check{I}}{4\,\omega}$$

The "reactive power" is the average flow of electromagnetic energy throughout one half-cycle from the instant that $W = o$ to the next instant that $W = o$ and since W is a double-frequency pulsating quantity whose average value is one half the maximum, the "reactive power" Q is given by $2\,\omega\,W$ or

$$Q = -\,j\,\frac{\check{E}\,\hat{I} - \hat{E}\,\check{I}}{2} \qquad (6)$$

multiply (6) by j and add to (4) we then have

$$P + J\,Q = \check{E}\,\hat{I}$$

This product therefore defines both the true and reactive power of the circuit.

The second terms of (3) and (5) are the double-frequency portions of the power product and we find if we take

$$P_H = \frac{\check{E}\,\check{I} + \hat{E}\,\hat{I}}{2}$$

$$Q_H = -\,j\,\frac{\check{E}\,\check{I} - \hat{E}\,\hat{I}}{2}$$

$$P_H + j\,Q_H = \check{E}\,\check{I}$$

The complete symbolic expression for the power is therefore

$$(P + j\,Q) + (P_H + j\,Q_H) = \check{E}\,\hat{I} + \check{E}\,\check{I}$$

The expression $P_H + J\,Q_H$ however is superfluous as we are only interested in the mean values of power and furthermore, when the values of P and Q are given, the values of P_H and Q_H may be determined. It may be shown that the vector $P_H + j\,Q_H$ which is rotating positively at double synchronous speed will be equal in

magnitude to $P + jQ$ and coincide with it at the same instant that the vector $\check{E}$ is in coincidence with it, and since it rotates in the positive direction with twice the angular velocity of $\check{E}$, it will always be in advance of $\check{E}$ by the same angle that $\check{E}$ is in advance of the stationary vector $P + jQ$ (See Fig. 1).

In the case of wave-forms having harmonics it seems reasonable, since the heating effect of the harmonics

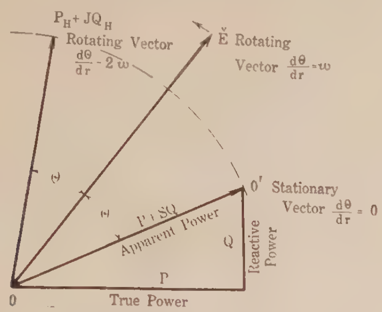


FIG. 1—VECTOR REPRESENTATION OF RELATION BETWEEN ZERO FREQUENCY POWER PRODUCT $(P + SQ)$ AND DOUBLE FREQUENCY POWER PRODUCT $(P_H\ SQ_H)$ IN SINGLE-PHASE CIRCUIT

is independent, to treat each frequency independently as to both true and reactive power so that if

$$\check{E} = \Sigma\, \check{E}_n$$
$$\check{I} = \Sigma\, \check{I}_n$$
$$P + jQ = \Sigma\, \check{E}_n\, \hat{I}_n = \Sigma\, (P_n + jQ_n)$$

and apparent power might then be defined by

$$\sqrt{P^2 + Q^2} = \sqrt{(\Sigma\, P_n)^2 + (\Sigma\, Q_n)^2}$$

MEASUREMENT OF POWER IN SINGLE-PHASE CIRCUITS

True power may of course be measured by a wattmeter in the usual way. To measure reactive power a wattmeter having a large inductance in series with the voltage coil may be used, connected into the circuit in the same way as the ordinary wattmeter. Assuming the resistance of the voltage coil to be negligible and taking i_0 for the current flowing in it, φ for the angle of the voltage coil relative to the current coil in which the current i is flowing (the current and voltage coils of a balance type instrument shouldbe in non-inductive relation and therefore $M = o$) we have

$$i_0 = 1/L \int^{i} e\, d\, t$$

The instantaneous torque is

$$F = \frac{\partial M}{\partial \varphi}\, i_0\, i$$
$$= 1/L\, \frac{\partial M}{\partial \varphi}\, i \int^{t} e\, d\, t$$

and the mean value of the torque is

$$F_{mean} = 1/L\, \frac{\partial M}{\partial \varphi}\, \frac{1}{2\,\pi} \int_0^{2\pi} i\, d\,\theta \int e\, d\, t$$
$$= \frac{1}{\omega\, L}\, \frac{\partial M}{\partial \varphi}\, Q$$

This arrangement therefore gives the mean magnetic energy, and when the frequency is known, the mean reactive power.

When the wave form of current and e. m. f. has harmonics this instrument gives the value of $2\, W_{mean}$ or the mean magnetic energy. If Q_n be the reactive power for the nth harmonic the quantity measured by the instrument is equal to $\Sigma \left(\frac{Q\, n}{n\, \omega} \right)$. There will therefore be a frequency error in the instrument.

MEASUREMENTS REQUIRED FOR COMPLETE DETERMINATION OF SINGLE-PHASE CIRCUIT

The following measurements or their equivalent are required to completely determine a single-phase current:

(1) Magnitude of impressed e. m. f.
(2) Phase of impressed e. m. f.
(3) Magnitude of current in circuit
(4) Phase of current in circuit.

For the last two, measurements of true and reactive power may be substituted. The second measurement is not required if the particular circuit only is under consideration. If we have measurements of e. m. f. kv-a. and power-factor, the circuit is completely determined and no other measurements are required.

MEASUREMENTS REQUIRED FOR COMPLETE DETERMINATION OF BALANCED POLYPHASE CIRCUIT

In a balanced system if e. m. f. and current are determined in one phase they will also be known in the other phases. The requirements are therefore the same as for single-phase and apply to one phase only which we shall call the "principal" phase.

REPRESENTATION OF POWER IN UNBALANCED THREE-PHASE CURRENTS

Confining ourselves to three-phase systems, we find that an unbalanced four-wire system required twelve measurements to define it completely or if expressed in symbolic form six quantities are required. If $A\ B\ C$ are the three phases these symbolic quantities may be

$$\left.\begin{matrix} \check{E}_A & \check{I}_A \\ \check{E}_B & \check{I}_B \\ \check{E}_C & \check{I}_C \end{matrix}\right\} \qquad (7)$$

In symmetrical coordinates the six quantities will be

$$\left.\begin{matrix} S^0\, \check{E}_{A0} & S^0\, \check{I}_{A0} \\ S'\, \check{E}_{A1} & S'\, \check{I}_{A1} \\ S^2\, \check{E}_{A2} & S^2\, \check{I}_{A2} \end{matrix}\right\} \qquad (8)$$

These are related to the quantities (7) by the simple relation

$$\left.\begin{aligned} S^0\, E_{A0} &= S^0\, \frac{\check{E}_A + \check{E}_B + \check{E}_C}{3} \\ S^1\, \check{E}_{A1} &= S^1\, \frac{\check{E}_A + \alpha\, \check{E}_B + \alpha^2\, \check{E}_C}{3} \\ S^2\, \check{E}_{A2} &= S^2\, \frac{\check{E}_A + \alpha^2\, \check{E}_B + \alpha\, E_C}{3} \end{aligned}\right\} \qquad (9)$$

where $\alpha = -1/2 + j\sqrt{3}/2$ $\alpha^2 = -1/2 - j\sqrt{3}/2$ exactly the same relations exist between $S^0 \check{I}_{A0}$ $S' \check{I}_{A1}$ $S^2 \check{I}_{A2}$ and $\check{I}_A \check{I}_B \check{I}_C$. We have also the reciprocal relations

$$\left.\begin{aligned} \check{E}_A &= \check{E}_{A0} + \check{E}_{A1} + \check{E}_{A2} \\ \check{E}_b &= \check{E}_{A0} + \alpha^2 \check{E}_{A1} + \alpha \check{E}_{A2} \\ \check{E}_C &= \check{E}_{A0} + \alpha \check{E}_{A1} + \alpha^2 \check{E}_{A2} \end{aligned}\right\} \qquad (10)$$

and corresponding relations between line currents and symmetrical coordinate currents. We sum the above up by the short hand expression

$$S^r(\check{E}_A) = S^0 \check{E}_{A0} + S^1 \check{E}_{A1} + S^2 \check{E}_{A2}$$

$$S^r(\check{I}_A) = S^0 \check{I}_{A0} + S^1 \check{I}_{A1} + S^2 \check{I}_{A2}$$

The terms prefixed by S^0 S^1 and S^2 are respectively called the zero-phase sequence, the positive phase sequence, and the negative phase sequence components of e. m. f. or current. The sequence symbol S prefixing each of the quantities, indicates that the quantity in question is the principal one of a group of three quantities constituting a symmetrical three-phase system.

For each current or e. m. f. sequence there is a conjugate current or e. m. f. sequence which is distinguished from it by having a negative exponent

$$\left.\begin{aligned} &S^0 \check{E}_{A0} \text{ conjugate seq } S^{-0} \hat{E}_{A0} \\ &S^1 \check{E}_{A1} \text{ conjugate seq } S^{-1} \hat{E}_{A1} \\ &S^2 \check{E}_{A2} \text{ conjugate seq } S^{-2} \hat{E}_{A2} \end{aligned}\right\} \qquad (12)$$

The relation between instantaneous values in the symmetrical coordinate system and the vector values is exactly the same as for single-phase. Thus the system of e. m. fs. $e_a\, e_b\, e_c$ is given by

$$(e_a, e_b, e_c) = \frac{S^0 \check{E}_{a0} + S^{-0} \hat{E}_{a0}}{\sqrt{2}} + \frac{S^1 \check{E}_{a1} + S^{-1} \hat{E}_{a1}}{\sqrt{2}} + \frac{S^2 \check{E}_{a2} + S^{-2} \hat{E}_{a2}}{\sqrt{2}}$$

The conjugate symbol S^{-1} is as it implies, a sequence which is conjugate to S^1. Thus, if $S^1 \check{E}_{a1}$ signifies the system

$$\left.\begin{aligned} \check{E}_{a1} &= \check{E}_{a1} \\ \check{E}_{b1} &= \alpha^2 \check{E}_{a1} \\ \check{E}_{c1} &= \alpha \check{E}_{a1} \end{aligned}\right\} \qquad (13)$$

The conjugate system $S^{-1} \hat{E}_{a1}$ is

$$\left.\begin{aligned} \hat{E}_{a1} &= \hat{E}_{a1} \\ \hat{E}_{b1} &= \alpha \hat{E}_{a1} \\ \hat{E}_{c1} &= \alpha^2 \hat{E}_{a1} \end{aligned}\right\} \qquad (14)$$

If we sum the terms of a sequence other than zero sequence the value will be always zero or

$$\Sigma (S^1 P) = 0$$

$$\Sigma (S^2 P) = 0$$

But $\Sigma (S^0 P) = 3P$ for three phase

Consider the system of e. m. fs. and currents e_a, e_b, e_c i_a, i_b, i_c. These two systems have been shown to be equal to

$$(e_a, e_b, e_c) = \frac{S^0 \check{E}_{a0} + S^{-0} \hat{E}_{a0}}{\sqrt{2}} + \frac{S^1 \check{E}_{a1} + S^{-1} \hat{E}_{a1}}{\sqrt{2}} + \frac{S^2 \check{E}_{a2} + S^{-2} \hat{E}_{a2}}{\sqrt{2}}$$

$$(i_a, i_b, i_c) = \frac{S^0 \check{I}_{a0} + S^{-0} \hat{I}_{a0}}{\sqrt{2}} + \frac{S^1 \check{I}_{a1} + S^{-1} \hat{I}_{a1}}{\sqrt{2}} + \frac{S^2 \check{I}_{a2} + S^{-2} \hat{I}_{a2}}{\sqrt{2}}$$

If we take the product of these two quantities treating the sequence symbols as if they represented actual quantities we shall obtain the instantaneous power in each of the phases. The zero-frequency portion of this quantity will be considered first as it represents the mean power in each phase. It will consist of two terms which are conjugate to each other. These two terms are those obtained by taking one half the product of $S^r(\check{E}_a)$ and $S^{-r}(\hat{I}_a)$ or $1/2\,(S^0 \check{E}_{a0} + S^1 \check{E}_{a1} + S^2 \check{E}_{a2})$ $(S^{-0} \hat{I}_{a0} + S^{-1} \hat{I}_{a1} + S^{-2} \hat{I}_{a2})$. From this, following the method of proof used for single-phase, we find that the mean power per phase may be represented by the vector sequence quantity $S^r(P_A + J\,Q_A)$. The mean power per phase obtained by taking the products of instantaneous values of current and e. m. f. is one half the sum of this term and its conjugate. Therefore the real part of this term represents the mean true power per phase and the imaginary part the mean flow of magnetic energy or the reactive power per phase. Using currents $i_A\, i_B\, i_C$ and e. m. fs. $e_A\, e_B\, e_C$ instead of $i_A\, i_B\, i_C$ etc.

$$\begin{aligned} S^r(P_A + j\,Q_A) &= (S^0 \check{E}_{A0} + S^1 \check{E}_{A1} + S^2 \check{E}_{A2})\,(S^{-0} \hat{I}_{A0} + S^{-1} \hat{I}_{A1} + S^{-2} \hat{I}_{A2}) \\ &= S^0 (\check{E}_{A0} \hat{I}_{A0} + \check{E}_{A1} \hat{I}_{A1} + \check{E}_{A2} \hat{I}_{A2}) \\ &\quad + S'(\check{E}_{A0} \hat{I}_{A2} + \check{E}_{A1} \hat{I}_{A0} + \check{E}_{A2} \hat{I}_{A1}) \\ &\quad + S^2 (\check{E}_{A0} \hat{I}_{A1} + \check{E}_{A1} \hat{I}_{A2} + \check{E}_{A2} \hat{I}_{A0}) \end{aligned} \qquad (15)$$

The symbol S^{-1} being in the three-phase system the same as S_1^2 and S^{-2} being the same as S^1. The total mean power is $P + j\,Q = \Sigma\, S^r(P_A + J\,Q_A)$ or

$$(P + j\,Q) = 3\,(\check{E}_{A0} \hat{I}_{A0} + \check{E}_{A1} \hat{I}_{A1} + \check{E}_{A2} \hat{I}_{A2}) \qquad (16)$$

$\Sigma\, S^1(\ )$ and $\Sigma\, S^2(\ )$ being both equal to zero represent instantaneous power interchanges among the three phases, and are caused by unbalance. The double-frequency power product $S^r(P_{HA} + J\,Q_{HA})$ is given by

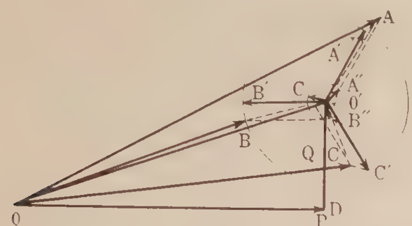
$$\begin{aligned} S^r(P_{HA} + j\,Q_{HA}) &= S^0 (\check{E}_{A0} \check{I}_{A0} + \check{E}_{A1} \check{I}_{A2} + \check{E}_{A2} \check{I}_{A1}) \\ &\quad + S^1 (\check{E}_{A0} \check{I}_{A1} + \check{E}_{A1} \check{I}_{A0} + \check{E}_{A2} \check{I}_{A2}) \\ &\quad + S^2 (\check{E}_{A0} \check{I}_{A2} + \check{E}_{A1} \check{I}_{A1} + \check{E}_{A2} \check{I}_{A0}) \end{aligned} \qquad (17)$$

which is seen to be the product

$(S^0 \check{E}_{A0} + S^1 \check{E}_{A1} + S^2 \check{E}_{A2})\,(S^0 \check{I}_{A0} + S^1 \check{I}_{A1} + S^2 \check{I}_{A2})$

and therefore the double-frequency product is obtained for three-phase in exactly the same way as it is obtained for single-phase, and furthermore, the amplitude and

three-phase angle of the double-frequency term for the principal phase is related to the e. m. f. of which it is composed in exactly the same way as in the case of single-phase. That is the double-frequency power vector is as much in advance of the corresponding e. m. f. vector as this vector is in advance of the corresponding mean power vector. The sequence of the double-frequency power vector is obtained from (**17**), that is the exponent of the sequence symbol or order of



$P + SQ = \Sigma \{S^0 \check{E}_{A1} \hat{I}_{A1} + \check{E}_{A2} \hat{I}_{A2}\} = 00'$

$(0' A'', 0' B'', 0' C'') = S^1 \check{E}_{A2} \hat{I}_{A1}$

$(0' A', 0' B', 0' C') = S^2 \check{E}_{A1} \hat{I}_{A2}$

$(0\ A,\ 0\ B,\ 0\ C\ )$ = Load per phase

FIG. 2—POWER VECTOR DIAGRAM

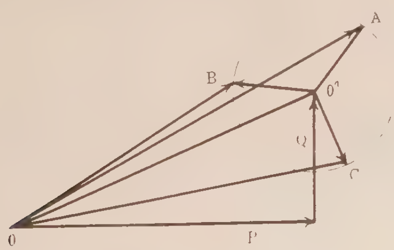
25 per cent current unbalance, 5 per cent voltage unbalance

the sequence is the sum of the exponents of the sequences of current and e. m. f.

The significance of the expression (**15**) is that it gives not only the mean power for each phase, but it also determines the magnitude and phase of the double-frequency power product which results from unbalance. The portions of (**17**) whose instantaneous sums are zero are of no significance. The important double-frequency quantities are given by

$$P_H + J\, Q_{H'} = \Sigma\, S^r\, (P_{HA} + Q_{HA})$$
$$= 3\, (\check{E}_{A0}\, \check{I}_{A0} + \check{E}_{A1}\, \check{I}_{A1} + \check{E}_{A2}\, \check{I}_{A2})$$

and are seen to be double-frequency power vectors of like value and phase in each phase. These power vectors are present only when there is unbalance and they have no relation to the power factor of the system.



$P + SQ = 3\, \check{E}_{A1} \hat{I}_{A1} = 00'$

$(0' A', 0' B', 0' C') = S' \check{E}_{A1} \hat{I}_{A2}$

$0 = S^2 \check{E}_{A2} I_{A1}$

(0A, 0B, 0C) = Load per Phase

FIG. 3—POWER VECTOR DIAGRAM

25 per cent current unbalance. No unbalance in voltage. Illustrates the load condition at a distribution point at which a phase balancer is installed.

In a balanced system the instantaneous sum of the double-frequency power vectors is always zero.

A power vector diagram for the zero frequency power products may be drawn. This vector diagram represents the resolution of the mean power per phase into symmetrical coordinate vectors. For each of these coordinates there is a corresponding double-frequency power vector which gives the actual value of the double-frequency power at each instant.

Fig. (3) illustrates a system having about 25 per cent unbalance in current and about 5 per cent unbalance in voltage. The relative distribution of load among the three phases will depend upon the position of the triangle $A\,B\,C$ which may be rotated about its centroid without changing the total mean power but producing a marked difference in the values of mean power per phase. The unbalance factor for current is the ratio $\check{I}_{A2}/\check{I}_{A1}$ which is a complex quantity. The conjugate of this quantity gives the magnitude and position of the unbalanced power vector $S^2\, \check{E}_{A1}\, \hat{I}_{A2}$ with respect to $S^0\, \check{E}_{A1}\, \hat{I}_{A1}$ the quantity which gives equal values per phase and is the total mean power product or kv-a. per phase.

The vector method of representing power quantities affords a simple means of obtaining a physical picture

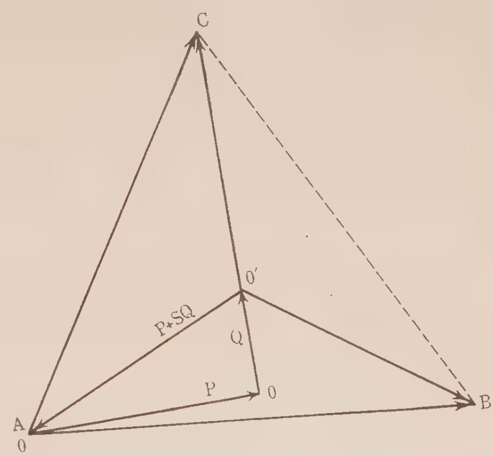


FIG. 4—POWER VECTOR DIAGRAM

Illustrates a single-phase load on a three-phase system, the balance of which is 100 per cent due to a phase balancer. $(O'\,A, O'\,B, O'\,C)$ represent the load on the balancer due to the single-phase load

of the heating effect due to unbalanced currents. In many cases the e. m. f. unbalance is small enough to be ignored in rough approximations. Take the case of a small induction motor having a negative phase sequence impedance of 15 per cent which is about an average figure; 3¼ per cent unbalance in voltage at the terminals of this motor will cause 25 per cent unbalance in current. From a practical standpoint in estimating the heating effect of the unbalance the voltage unbalance may be ignored. The mean power load will be practically the same as for balanced voltages with the addition of the kv-a. per phase due to the unbalanced current which will be added vectorially to the mean power; this will be obtained by taking the square of the unbalanced current multiplied by the negative sequence impedance. The end of this vector obtained in this manner serves as a centroid for an equilateral triangle $A'\,B'\,C'$ such that the lines drawn from the centroid to A, B, and C, are equal to 25 per cent

of the mean power per phase or the vector $S^0 \check{E}_{A1} \hat{I}_{A1}$. By rotating this triangle about its centroid all the different conditions of load to which the motor may be subjected on a line having this degree of unbalance are obtained. The triangle A', B', C' is drawn negative sequence. If we wish also to include the unbalance due to the voltage we may represent this by a positive phase sequence equilateral triangle whose distance from centroid to apex is $3\frac{1}{4}$ per cent of the mean power per phase. The angle this vector makes with the mean power vector is arbitrary and is the same as the angle $\check{E}_{A2}$ makes with E_{A1}. Let us denote it by θ_1. Let θ_3 be the angle that the negative sequence current lags behind the negative sequence voltage, this is given by the power factor of the negative phase sequence impedance. Then the principal phase or apex A'' will be in advance of the datum line by the angle $\theta_3 - \theta$. To obtain a complete solution we should take

(1) mean power per phase $P/3 + j\,Q/3$ leads datum line by angle θ_2

(2) neg. seq. power per phase $\check{E}_{A2} \hat{I}_{A2}$ length of vector compared with $(P/3 + j\,Q/3)$ is given by product of current unbalance factor and voltage unbalance factor leads datum line by angle θ_3.

(3) voltage unbalance volt. amp. $S^1 \check{E}_{A2} \hat{I}_{A1}$ length of vector compared with $(P/3 + j\,Q/3)$ same percentage as $\check{E}_{A2}$ is of $\check{E}_{A1}$ leads datum line by angle $\theta_2 + \theta_1$

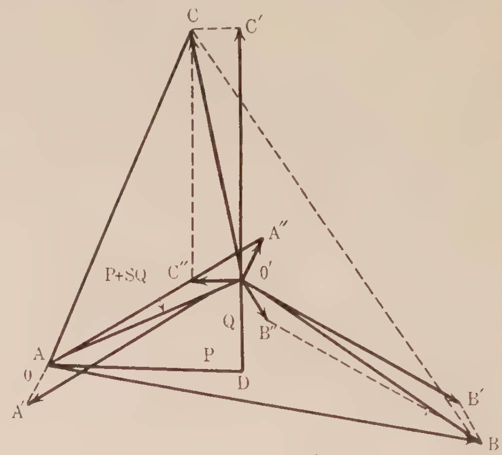
(4) current unbalance volt amperes $S^2 \check{E}_{A1} \hat{I}_{A2}$ length of vector compared with $P/3 + j\,Q/3$ or $\check{E}_{A1} \hat{I}_{A1}$ is same percentage as $\hat{I}_{A2}$ is of $\hat{I}_{A1}$ or unbalance factor leads datum line by angle $\theta_3 - \theta_1$.

Each of the systems of vectors $S^2 \check{E}_{A1} \hat{I}_{A2}$, $S^1 \check{E}_{A2} \hat{I}_{A1}$ will give an equilateral triangle whose centroid is the end of the vector $S^0 (\check{E}_{A1} \hat{I}_{A1} + \check{E}_{A2} \hat{I}_{A2})$. The two combine to form a triangle not equilateral which may be rotated about its centroid at the end of the mean power vector to give the power per phase for all possible conditions of load, thus the complete range of possible values of kv-a. per phase may be obtained by the lengths of the vectors $O\,A$, $O\,B$, $O\,C$ drawn from the origin to the apices of the composite triangle.

A study of the diagram will show that the quantities measuring unbalance do not affect the true mean power and power factor, and therefore any attempt to deduce a factor which will simultaneously take account of both power factor and unbalance is useless. The positive and negative sequence current, voltage, true power, reactive power, etc. may all be measured with single element meters and a suitable constraining network. Mr. Evans has kindly undertaken to describe in the discussion some of those which have been developed.

Applying the principles outlined above it is easy to prove that a symmetrical generator can deliver power only through the positive phase sequence current it delivers to the system, and that any power due to negative phase sequence current is absorbed as losses in the generator. This is also true of all symmetrical rotating machines on the system, any power due to negative phase sequence current is absorbed in the form of additional losses.

In the body of the paper the task has been undertaken of showing that unbalance is of the same order of importance as power factor. If we denote by $\check{E}_1$ the terminal e. m. f. of one winding of a generator and by $\check{E}_0$ the e. m. f. that would appear at the terminals if



$$P + SQ \quad (\acute{E}_{A1}\, \dot{I}_{A1} - \dot{I}_{A1}\, Z_1)\; \dot{I}_{A1} - I_{A1}^2\, Z_2$$

$$0A',\ 0B',\ 0C' = -S^2 (\check{E}_{A1}\, \check{I}_{A1} - \dot{I}_{A1}\, Z_1)\, \dot{I}_{A1}$$

$$(0A'',\ 0B'',\ 0C'') = S^1 I_{A1}^2 Z_2$$

$$\check{I}_{A1} = -\dot{I}_{A2}$$

Fig. 5—Power Vector Diagram

Single-phase generator supplying power ($O\,A$, $O\,B$, $O\,C$) represent loads on phase A, B and C respectively

the current were zero, and if $r_1\,I$ be the resistance drop $j \times \check{I}_1$ the e. m. f. due to the component of the field set up by the stator m. m. f. including the internal leakage field

$$\check{E}_0 = \check{E}_1 + (r_1 + j\,x_1)\,I_1$$

The phase and magnitude of $\check{E}_0$ will depend upon the time phase of I_1. Since $\check{E}_0$ is the component due to the exciting current I_0 we may use the coefficient of mutual induction M_0 to give the generated voltage in terms of the exciting current

$$\check{E}_0 = j\,\omega\,\dot{M}_0\,I_0\,e^{jwt}$$

and therefore

$$j\,\omega\,\dot{M}_0\,I_0\,e^{jwt} = \check{E}_1 + (r_1 + j\,x_1)\,I_1$$

In particular if we take E_1 as datum and if $\check{I}$ is lagging in time phase behind E_1 by a quarter cycle

$$j\,\omega\,\dot{M}_0\,I_0\,e^{jwt} = E_1\,e^{jwt} + (r_1 + j\,x_1)\,(-\,j\,I_1)\,e^{jwt}$$

$$j\,\omega\,\dot{M}_0\,I_0 \qquad = (E + x_1\,I) - (j\,r\,I)$$

Thus if we ignore the value of $r_1\,I_1$ which is small, the increase in the exciting current required to maintain a given terminal e. m. f. under zero power factor load is proportional to I

$$\Delta\,I_0 = \frac{x_1}{j\,\omega\,M_0}$$

showing that the presence of wattless lagging current in the winding necessitated a proportional increase in the exciting current. The cyclic changes in saturation will not affect the value of M_0 which is the average

value. But the average value will change with the strength of the resultant field, but on account of the long air gaps, these changes are not so important as might be supposed.

When the terminal voltages are unbalanced they may be resolved into their positive and negative phase sequence components $S' \check{E}$ and $S^2 \check{E}_2$ so that we have

$$S \check{E} = S^t \check{E}_1 + S^2 \check{E}_2$$

we have further

$$S^1 \check{E}_1 = S' (j\,\omega\, M_0\, I_0\, e^{j\omega t} - Z_1\, \check{I}_1)$$
$$S^2 \check{E}_2 = S^2 (o - Z_2\, \check{I}_2)$$

the generated negative sequence voltage in a symmetrical generator being zero. This gives

$$S^1 \check{E}_0 = S^2 (\check{E}_1 + Z_1\, \check{I}_1)$$
$$S^2\, o = S^2 (\check{E}_2 + Z_2\, \check{I}_2)$$

The total current is

$$S^r (\check{I}) = S^1 \check{I}_1 + S^2 \check{I}_2$$

conjugate $S^{-r} (\hat{I}) = S^{-1} \hat{I}_1 + S^{-2} \hat{I}_2$

The power generated

$$P_0 + j\, Q_0 = \Sigma\, [\, S^1 \check{E}_0 + S^2 (o)\,]\, [S^{-1} \hat{I}_1 + S^{-2} \hat{I}_2] = 3\, (\check{E}_0\, \hat{I}_1)$$

which shows that no power is generated through negative sequence current, but such as appears at the generator terminals is power that was originally generated by the machine through positive sequence voltage and current which has been degraded through some unbalanced load and fed back into the system in the form of negative phase sequence voltage and current, producing increased losses and heating.

The total heating due to $\check{I}_2$ in the stator windings will be obtained correctly by considering $\check{I}_2$ as entirely independent of $\check{I}_1$. The losses due to the double-frequency current in the rotor which arises from $\check{I}_2$ will also cause independent heating so that the total copper loss in the machine is obtained by the power product $3\, (I_1^2\, Z_1 + I_2^2\, Z_2)$, the real part being the true copper loss. This may be obtained by considering the output of the machine at its terminals; this is given by

$$P + j\, Q = \Sigma\, (S^r\, \check{E}_A \times S^{-r}\, \hat{I}_A)$$

$\check{E}_A$ being the terminal voltage and $\hat{I}_A$ the conjugate of the terminal current with particular reference to phase A as principal phase

$$S^{-r}\, \check{I}_A = S^1\, \check{I}_1 + S^2\, \hat{I}_2$$
$$\check{I}_A = \check{I}_1 + \check{I}_2$$
$$\check{I}_B = \alpha^2\, \check{I}_1 + \alpha\, \check{I}_2$$
$$\check{I}_C = \alpha\, I_1 + \alpha^2\, \check{I}_2$$

and the terminal e. m. f.

$$S^r\, \check{E}_A = S' (\check{E}_0 - \check{I}_1\, Z_1) - S^2\, \check{I}_2\, Z_2$$
$$\check{E}_A = \check{E}_0 - Z_1\, \check{I}_1 - Z_2\, \check{I}_2$$
$$\check{E}_B = \alpha^2\, \check{E}_0 - Z_1\, \alpha^2\, \check{I}_1 - Z_2\, \alpha\, \check{I}_2$$
$$\check{E}_C = \alpha\, \check{E}_0 - Z_1\, \alpha\, \check{I}_1 - Z_2\, \alpha^2\, I_2$$

where $\alpha = -1/2 + j\,\sqrt{3}/2$ $\alpha^2 = -1/2 - j\,\sqrt{3}/2$ $\alpha^3 = 1$

$$\begin{aligned}\Sigma\, (S^r\, \check{E}_A\, .\, S^{-r}\, \hat{I}_A) &= \Sigma\, [\, S' (\check{E}_0 - Z_1\, \check{I}_1) - S^2\, Z_2\, \check{I}_2]\, (S^{-1}\, \hat{I}_1 + S^{-2}\, \hat{I}_2)\\ &= \Sigma\, [\, S^0\, (\check{E}_0\, \hat{I}_1 - Z_1\, I_1^2) - S^0\, I_2^2\, Z_2 + S^2\, (\check{E}_0 - \check{I}_1\, Z_1)\, \hat{I}_2 - S'\, \check{I}_2\, \hat{I}_1\, Z_1\\ &= 3\, (\check{E}_0\, \hat{I}_1 - I_1^2\, Z_1 - I_2^2\, Z_2)\end{aligned}$$

$3\, \check{E}_0\, \hat{I}_1$ is the output of the generator not including the copper losses. The real part of $(I_1^2\, Z_1 + I_2^2\, Z_2)$ therefore gives the total copper loss.

The solution of the system may of course be obtained by the methods used in ordinary linear circuits having mutual inductances. If we have a three-phase machine with winding impedances $Z_{11}\, Z_{22}\, Z_{33}$ and mutual impedances $Z_{12}\, Z_{23}\, Z_{31}$ etc. we have the following relations in a symmetrical machine

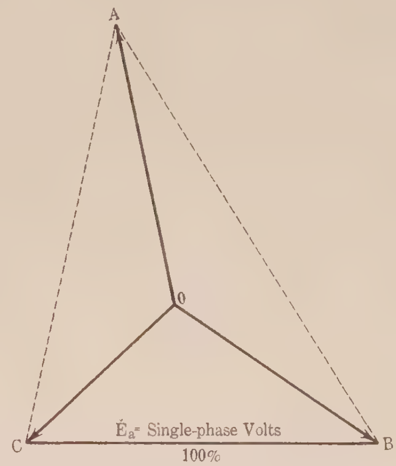


FIG. 6—VECTOR DIAGRAM OF E. M. FS.
Single-phase generator supplying power. Obtained from Fig. 5

$$Z_{11} = Z_{22} = Z_{33} = Z_1 + Z_2$$
$$Z_{12} = Z_{23} = Z_{31} = \alpha^2\, Z_1 + \alpha\, Z_2$$
$$Z_{13} = Z_{21} = Z_{32} = \alpha\, Z_1 + \alpha^2\, Z_2$$

Conversely we have for Z_1 and Z_2 in terms of the impedances $Z_{11}\, Z_{12}$ etc.

$$Z_1 = \frac{Z_{11} + \alpha\, Z_{12} + \alpha^2\, Z_{13}}{3}$$

$$Z_2 = \frac{Z_{11} + \alpha^2\, Z_{12} + \alpha\, Z_{13}}{3}$$

The equations of the generator in terms of the impedances $Z_{11}\, Z_{12}$ etc. are

$$\left.\begin{aligned}\check{E}_A &= \check{E}_0 - Z_{11}/3\; \check{I}_A - Z_{21}/3\; \check{I}_B - Z_{31}/3\; \check{I}_C\\ \check{E}_B &= \check{E}_0 - Z_{12}/3\; \check{I}_A - Z_{22}/3\; \check{I}_B - Z_{32}/3\; \check{I}_C\\ \check{E}_C &= \check{E}_0 - Z_{13}/3\; \check{I}_A - Z_{23}/3\; \check{I}_B - Z_{33}/3\; \check{I}_C\end{aligned}\right\} \quad (18)$$

The relations

$$\left.\begin{aligned}\check{I}_A + \check{I}_B + \check{I}_C &= 0\\ Z_{11} + Z_{12} + Z_{13} &= 0\\ \check{E}_A + \check{E}_B + \check{E}_C &= 0\end{aligned}\right\} \quad (19)$$

reduce the number of independent variables in these equations to two but there is not much simplification introduced.

The above solution illustrates the difference between the method of solution which consists in considering each phase as an independent single-phase circuit and that in which the effects of the currents in all phases in symmetrical groups are considered simultaneously. Equations (**18**) and (**19**) are the forms to which the differential equations reduce on solution for steady conditions. The impedances $Z_{11}\ Z_{12}\ Z_{12}$ etc. are compounded of two impedances Z_1 and Z_2 which are fundamental characteristic impedances of the machine and it is interesting to note that the form of these impedances bears the same relation to Z_1 and Z_2 that the currents $\check{I}_A\ \check{I}_B\ \check{I}_C$ bear to $\check{I}_1$ and $\check{I}_2$.

Three-Phase Power Measurements

It is convenient to represent line currents, and, e. m. fs. measured from the neutral point, by $\check{I}_A\ \check{I}_B\ \check{I}_C$, $\check{E}_A\ \check{E}_B\ \check{E}_C$ respectively and the corresponding sequence quantities by $S^0\ \check{I}_{A0}\ S^1\ \check{I}_{A1}\ S^2\ \check{I}_{A2}$ etc. Delta currents and e. m. fs. between lines are represented by $\check{I}_a\ \check{I}_b\ \check{I}_c\ \check{E}_a\ \check{E}_b\ \check{E}_c$ as shown in Fig. (7) the positive direction being indicated by an arrowhead. This gives the

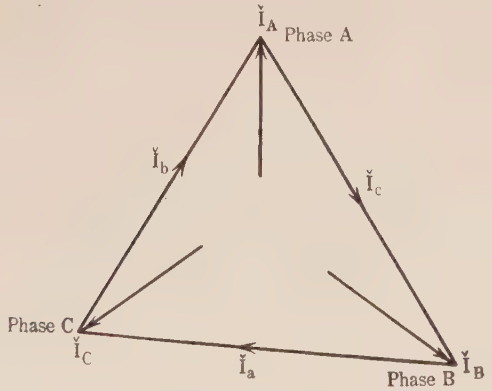


Fig. 7—Diagram Illustrating Convention Used in Star and Delta Currents by Symmetrical Coordinates

following relations between the line currents, delta currents, Y voltages and delta voltages

$$S^r\ \check{E}_A = S^1\ \check{E}_{A1} + S^2\ \check{E}_{A2}$$

$$S^r\ \check{E}_a = S^1 j\sqrt{3}\ \check{E}_{A1} - S^2 j\sqrt{3}\ \check{E}_{A2}$$

So that $\quad S^1\ \check{E}_{a1} = S^1 j\sqrt{3}\ \check{E}_{A1}$

$$S^2\ \check{E}_{a2} = S^2 - j\sqrt{3}\ \check{E}_{A2}$$

With these relations the various methods of measuring power in three-phase circuits may be easily proved.

Three-Phase Power with Two Wattmeter

$$P + jQ = \Sigma\,(S^1\ \check{E}_{A1} + S^2\ \check{E}_{A2})\,(S^{-1}\ \hat{I}_{A1} + S^{-2}\ \hat{I}_{A2})$$
$$= \Sigma\,[\,S^0\,(\check{E}_{A1}\ \hat{I}_{A1} + \check{E}_{A2}\ \hat{I}_{A2}) + S^2\ \check{E}_{A1}\ \hat{I}_{A2} + S^1\ \check{E}_{A2}\ \hat{I}_{A1}]$$

The sum of the instantaneous values of all but the S^0 group is zero. We may therefore add to the e. m. f. any quantity which will give S^1 and S^2 groups with no S^0 group without changing the value of the S^0 term. Thus if we add to $S^r\ E_A$ any S^0 term we shall not change the mean power. If we add $-\ S^0\ (\check{E}_{A1} + \check{E}_{A2})$; this will make the power in phase A zero. The wattmeter in this phase may therefore be dispensed with. This will add $-\ S^2\,(\check{E}_{A1}\ \hat{I}_{A2} + \check{E}_{A2}\ \hat{I}_{A1})$ and $-\ S^1\,(\check{E}_{A1}\ \hat{I}_{A2} + \check{E}_{A2}\ \hat{I}_{A2})$ to the power product. The voltages will be

$$\check{E}_A = \check{E}_{A1} + \check{E}_{A2} - \check{E}_{A1} - \check{E}_{A2} = 0$$

$$\check{E}_B = \alpha^1\ \check{E}_{A1} - \check{E}_{A1} + \alpha\ \check{E}_{A2} - \check{E}_{A2} = \check{E}_C$$

$$\check{E}_C = \alpha\ \check{E}_{A1} - \check{E}_A + \alpha^2\ \check{E}_{A2} - \check{E}_{A2} = -\ \check{E}_B$$

We have therefore the line currents $\check{I}_B\ \check{I}_C$ in the series coils and the voltages E_B and $-\ E_C$ across the shunt coils. It should be noticed that the addition of S^0 in any quantity to the e. m. f. will not affect the mean power, and therefore we may impress the voltage to the lines from any convenient point without changing the mean power. Graphically this is shown by the fact that the S^0 power product determines the mean power and the centroid of the triangles defining the amount of unbalance. Displacing the neutral point merely adds S' and S^2 products to the power and these represent equilateral triangles having their centroids coinciding with the end of the mean power factor.

Single-Phase Generator

In the single-phase generator we have a generated symmetrical e. m. f. $\check{E}_0$ and at the terminals e. m. fs. $S_1\ \check{E}_{A1}$ and $S^2\ \check{E}_{A2}$. Furthermore if $S^1\ I_{A1}$ be the positive phase sequence current $-\ S^2\ I_{A1}$ will be the negative phase sequence current and therefore

$$S^1\,(\check{E}_0 - Z_1\ \check{I}_{A1}) = S^1\ \check{E}_{A1}$$

$$S^2\ \check{E}_{A2} = S^2\ Z_2\ \check{I}_{A1}$$

Then $\quad S^1\ \check{E}_{A1} + S^2\ \check{E}_{A2} = S^1\,(\check{E}_0 - Z_1\ \check{I}_{A1}) + S^2\ Z_2\ \check{I}_{A1}$

$$S\,(P_A + J\,Q_A) = S^0\,(\check{E}_0 - Z_1\ \check{I}_{A1})\ \hat{I}_{A1} - S^0\,(Z_2\ I_{A1}^2) - S^2\,(\check{E}_0 - Z_1\ \check{I}_{A1})\ \hat{I}_{A1} + S^1\,(Z_2\ I_{A1}^2)$$

The mean output per phase $P + j\,Q$ is therefore $S^0\,(\check{E}_0 - Z_1\ \check{I}_{A1})\ \hat{I}_{A1} - S^0\,(Z_2\ I_{A1}^2)$ so that the addition of the vectors $-\ S^2\,(\check{E}_0 - Z_1\ \check{I}_{A1})\ \hat{I}_{A1} + S^1\,(Z_2\ I_{A1}^2)$ makes the power in the A phase zero as it should be.

The vector diagram may be drawn as follows: Draw from the origin O the line $O\,O'$ equal to $P + j\,Q$. The value of I_{A1} is known it is $P + j\,Q$ divided by the Y voltage corresponding to the value of the single-phase terminal voltage. Through the point o' draw the vectors $S^1\ I_{A1}^2\ Z_2$ giving $O'\,A''\ O'\,B''\ O'\,C''$ in positive phase sequence relation. Draw $O'\,A'$ parallel and equal to $A''\,O$, $O'\,A'$ will then be the principal vector of the system $-\ S^2\,(\check{E}_0 - Z_1\ \check{I}_{A1})\ \hat{I}_{A1}$. Complete the system by the lines $O'\,B'\ O'\,c'$ in negative sequence relation with $o'\,A'$. The resultant of the systems $S'\ I_{A1}^2\ Z_2$ and $-\ S^2\,(\check{E}_0 - Z_1\ \check{I}_{A1})\ \hat{I}_{A1}$ represented respectively by the equilateral triangles $A''\,B''\,C''$ and $A'\,B'\,C'$ combined give the triangle $A\,B\,C$ of which the apex A lies on the point O and the lines $O\,B$ and $O\,C$ represent the power delivered by the phases B and C and these vectors are also proportional to the voltage to neutral of these two phases under load. The datum of $P + j\,Q$ represents also the phase of $\check{I}_B$ and $\check{I}_C$ in drawing the diagram. Fig. 6.

A Diaphragmless Microphone for Radio Broadcasting

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THE broadcasting of regular programs of entertainment and instruction was begun in the Fall of 1920. It was not long before the service became quite generally used, although at first this was due to its novelty. Judged by present standards, the character of the programs rendered, and the quality of modulation attained, was susceptible to great improvement; and the development of better apparatus and methods of modulation has gone hand in hand with the broadening of the scope of entertainment offered.

At the time when the writer's attention was directed to this matter, the gradual improvement being made in the speech amplifier and modulator system, was making it increasingly evident that the carbon granule microphone could not be relied upon for accurate reproduction of music.

In order to transform sound vibrations, without distortion, into electrical vibrations in the ether, given a distortionless amplifying system, certain conditions must be met by the reproducing device. These, briefly, are as follows:

1. An incident sound wave, of a given pitch and intensity, must always have the same effect upon the microphone..
2. There must be a linear relation between sound intensity and effect produced.
3. The device must be critically damped, in order to correctly copy complex sound waves.
4. There must be no resonance points in the curve of variation of response with frequency, which should preferably be a straight line parallel to the frequency axis.
5. It is very desirable that this curve of response against frequency, be to some extent adjustable at the microphone. This is desirable in order to be able to correct for attenuation in overhead or cable lines from the signal source to the broadcasting station.

The carbon granule microphone depends for its action upon the variation of contact resistance between numbers of carbon particles. This variation is caused by movement of a diaphragm, actuated in turn by the incoming sound waves. When used for voice transmission in the usual way, an average intensity of reproduction will be maintained over indefinite periods because the speaker talks directly into the mouthpiece, causing a considerable agitation of the granules. In reproducing music comprising more than one tone, or one instrument, it is not feasible to direct the sound waves into the mouthpiece, and a much diminished sound intensity must be employed. This results in a gradual loss of sensitivity of the microphone,—the familiar "packing",—so that the first of the above conditions cannot be met. Conditions (2) and (3) are complied with, approximately, over fairly wide limits. The use of a loaded diaphragm, however, means that there will be a fundamental or natural period and its overtones, due to the instrument itself. At these frequencies the response will, by mechanical resonance, be much exaggerated. Usually this fundamental frequency is purposely placed at or near eight hundred cycles, the figure adopted as the average speech frequency. This means that below the natural frequency, the response increases with frequency, rising to a peak as resonance is reached, and falling off rapidly at higher frequencies. The timbre of the various musical instruments is due to the frequency and intensity of the various harmonics present. These occur mainly in the range above eight hundred or one thousand cycles,—the range through which the sensitivity of the carbon microphone is low and decreasing. All such microphones, to a greater or lesser extent, have undesirable characteristics such as described; hence it is apparent that one cannot expect faithful reproduction of music by this means.

The carbon microphone is ordinarily used to vary the current in a circuit, supplied at constant potential, by varying the resistance of the microphone. Since in the Ohm's law equation for current, directly applicable, the circuit resistance appears in the denominator, the current variation cannot be an exact copy of the resistance variation. The distortion will be the greater, the larger is the proportion of microphone resistance to total resistance in circuit. In other words, the greater the sound intensity at the diaphragm,—which tends to prevent packing,—the more will the reproduction be distorted.

It was found possible to remove this cause of distortion by using the microphone in a constant current circuit, instead of one worked at constant potential. By connecting the instrument in series with either a high resistance or high inductance, and securing proper current by adjustment of the supply voltage, the current will remain constant, and the potential at the microphone terminals will be directly proportional to the resistance, instead of inversely. By suitable amplification of this voltage variation, much better quality can be obtained; however, the resonance characteristics and the unsteady performance cannot be improved in this way.

Although it was found possible to correct, in some measure, the tendency to resonance, it was felt that such devices are by their very nature unsuited to the purpose in hand.

The first alternative taken up was an electrodynamic

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or moving coil transmitter, whose coil was connected to the center of a diaphragm clamped at its edge, which moved the coil in a strong magnetic field. If connected in a circuit of large inductance and low resistance, the movement of the diaphragm will cause alternating currents to flow in the coil circuit. These currents will be, for sound waves of constant amplitude, independent of the sound frequency. Proper corrugation of the diaphragm will annul any harmonic resonance, leaving the fundamental period alone to be corrected for. Hence the response curve will be of the same shape as an electrical resonance curve, and may be corrected in the amplifying network, by the use of suitable filters.

It was shown experimentally that such a transmitter could be produced. The compensation was satisfactory in the lower and intermediate audio ranges, but at the higher frequencies mechanical hysteretic effects in the diaphragm became prominent, and the resonance characteristics of the moving coil and connection system came into play, so that the results could not be considered satisfactory.

At about this time, advantage was taken of the condenser transmitter, developed primarily for use in measurements of sound intensity.[1] This instrument left, theoretically, little to be desired, since it had been shown[2] to be possible to construct it with critical damping and with a response characteristic practically independent of frequency. However, it developed after several months' use in broadcasting, that the problem of maintaining its insulation resistance high and constant, to avoid loss of sensitivity and introduction of ground tone, is difficult of solution. There is also a marked tendency for the diaphragm, originally tightly stretched, to sag and lower its natural frequency until it comes well within the audio range, which defeats the primary object of the construction. The high order of impedances involved, as well as the considerable amount of amplification required, make the instrument difficult to maintain in satisfactory operating condition. Even with these defects, however, the condenser transmitter represents practically the best solution of the problem of sound reproduction by use of a diaphragm. It thus became apparent that the production of a diaphragmless microphone would be a distinct step forward.

There are several ways in which sound waves may be electrically reproduced without the use of a diaphragm. In many cases, however, while fundamental frequencies and resonant harmonics are avoided, the mechanism employed is not free from inertia. This is true, for example, in the case of the inverted Goldschmidt thermophone, in which the sound waves vary the temperature and hence the resistance of a heated wire or strip. The sensitivity may be made independent of frequency, in such cases, by damping the lower ranges, but its value will then be no greater than the undamped value at the highest frequency used. The required amplification thus becomes so large that the ratio of tube noise to signal is difficult to keep small enough for quiet operation.

The variation of the impedance of an ionic stream, as the pressure is varied by the incident sound waves, offers great promise, especially if so-called cold ionization can be used. In this case there will be practically no energy loss, no heat developed, and hence no inertia at the instrument. Calculations, however, of the space current to be expected in air at atmospheric pressure, with radium or emanation as source, showed that the impedances to be expected would be of even higher order than those in the condenser transmitter circuits. Experimental tests showed the same to be true of ionization currents due to ultraviolet light.

An operative microphone was made by using the ionization from a Nernst glower. The response curve fell off very badly as the frequency was raised. It was found to be impossible to eliminate the hum caused by the commutator of the dynamo furnishing the current to heat the Nernst glower. Following this lead, it was found that the response was due in the main to change of temperature of the glower, and not to direct change of impedance due to the sound wave. This explained the mass or inertia effect found to be present.

At this time the writer's attention was brought to the relatively great change in potential across a so-called "glow-discharge," at reduced pressures, which is known to occur upon altering the length of discharge path. It was suggested that something of the same effect might be present in air at atmospheric pressure. A calculation showed that this effect would afford ample sensitivity at reasonable impedance, were it to be even one hundredth as great in open air as at the pressures employed in the published work. Tentative tests were made along this line, which seemed to show that the sensitivity in open air would not be sufficient for the purpose; also it was necessary to use a diaphragm. The writer, however, was able to show that the discharge impedance could be varied directly, without the intermediary diaphragm, by pressure variation from sound waves reaching the discharge path.

The direct-current glow discharge, at low pressure, is a fairly well known form of ionization conduction, little has been published, however, on its characteristics in open air. Since the new microphone makes use of such a discharge as its variable impedance, a brief description of the phenomena is thought to be desirable.

The application of moderately high direct potential between two electrodes separated a short distance in air, with enough series resistance to prevent formation of the usual type of heavy current arc, will cause the establishment of a peculiar low current, high voltage discharge having a characteristic glowing appearance, from which is derived the name, "glow-discharge."

1. E. C. Wente, *Phys. Rev.*, II, Vol. 10, p. 39, 1917.
2. I. B. Crandall, *Phys. Rev.*, II, Vol. 11, p. 449, 1918

The order of current is from one to twenty milliamperes or more, at voltages ranging from two or three hundred to one thousand volts.

Such a discharge, when produced between electrodes of certain metals, of which copper is one of the best, is remarkably quiet and steady to the unaided ear and eye. The discharge path is similar to that produced at low pressure, except that certain portions are of much less length. There are eight portions, of which but four are of importance in the open air. Fig. 1, schematic, shows these portions, which comprise, as we go from the anode towards the cathode; the anode glow, the anode column, the Faraday dark space, and the cathode glow. Between the cathode glow and the negative electrode there is a second dark space, called

Fig. 1—Enlarged (Schematic) Appearance of Glow Discharge

the Crookes' or cathode dark space. The potential drop across this space is quite large, but its length in open air is very short.

If such a discharge be connected as shown in Fig. 2, it is found that the incidence of sound waves at the gap will produce alternating potentials of equivalent frequencies across the coupling condenser *C*, whose function is to block off the direct potential drop from the grid of the amplifier tube *A*. The rectifier tube shown in the discharge circuit serves to maintain the current at a constant value as the discharge impedance changes with varying pressure. The sensitivity is surprisingly large; an amplification of ten to one will give loud signals in a head set. The discharge imped-

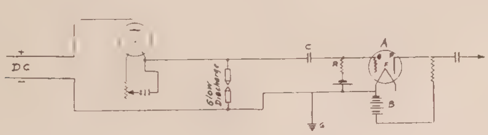

Fig. 2—Diagram of Connections, Constant Current Glow Discharge, Showing First Step of Amplification

ance is of the order of five hundred thousand ohms, which is low enough to cause no trouble in maintaining insulation resistance, or in adapting the device for use with standard vacuum tubes.

Equipment of this nature was tried out in formal broadcasting from station *K D K A*, in the spring of 1922. The discharge gap or holder used is shown diagrammatically in Fig. 3. The following defects were found to be present:

1. The curve of sensitivity as function of frequency was not flat, but fell off considerably at the higher frequencies.

2. There was considerable "ground tone,"—rumbling, hissing and popping noises not connected with the sounds being copied. These noises were not prominent enough to interfere with the modulation, but were quite disagreeable during quiet intervals. At times they were strong enough to cause overmodulation of the system.

3. As was to be expected, there was extreme sensitiveness to drafts or air currents, because no draft shields had been attached to the discharge holder. The sudden opening of a door into the studio would cause enormous variations in gap voltage. The blocking condenser *C* of Fig. 2 thus became overcharged, the potential on the first amplifier grid was made positive, and the sensitivity to sound was entirely lost until the condenser could discharge through the grid leak.

4. There was a certain amount of radio frequency regeneration.

These defects were sufficiently pronounced to make the device unsuitable for use in broadcasting. The advantages afforded, namely simplicity, durability, low impedance, and high sensitivity, in addition to elimination of the diaphragm, were so great that it was decided to see what could be done in the way of improvement. The matter of unequal response with

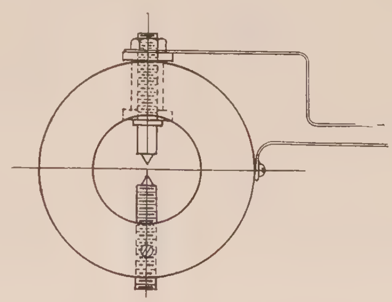

Fig. 3—First Glow Discharge Microphone

varying frequency was taken up first, being the most serious defect. To avoid loss of sensitivity, it was desirable if possible to reinforce the weak portions of the curve, rather than to cut down the stronger portions. Unsuccessful attempts were made to do this by the use of various designs of single and double amplifying horns. It finally became necessary to make a study of the sound response of the different portions of the discharge, to find out what if any portions would give proper response. This was accomplished by the use of a perforated exploring electrode, through which the discharge was allowed to pass. As shown in Fig. 4, connection to the amplifier grid could be made from the exploring electrode and either terminal of the discharge. The most sensitive portion was found to be the positive column. Its sensitivity was so great that when using the whole gap, as in Fig. 2, but little was contributed by the other parts of the discharge. The sensitivity of the portion from the end of the positive column to the cathode terminal was found to be much less than that of the positive column, and to be independent, through wide limits, of frequency. While more amplification

is required when the positive column effect is eliminated, the effect of frequency can be made negligible.

It will now be apparent that by suitably proportioning the discharge gap, and properly placing the exploring electrode, we can control, to a great extent, the shape of the frequency response curve. It should be noticed here that as the separation of the main electrodes is increased, nothing in the character of the discharge is altered, except the length of the positive column and the voltage drop across this column. The positive column gradient is roughly fifteen hundred volts per centimeter of length. If a short gap is used, with the exploring electrode close to the cathode terminal, the response will be obtained mainly from the cathode and will be practically flat. If the gap is lengthened, without altering the distance from cathode to exploring electrode, the differential action of the cathode portions and the positive column, on the voltage change at the exploring electrode, will result in partial suppression of the response on the lower audio register. An upward sloping curve will result. As the exploring electrode is moved nearer to the anode end, the positive column characteristic will become gradually

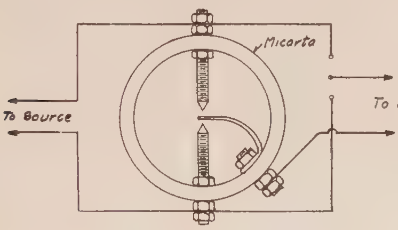

Fig. 4—Glow Discharge Microphone with Exploring Electrode

more dominant, until at the limit, when the whole gap is used as pick-up, the characteristic will have a pronounced downward slope. The use of this microphone, therefore, should enable one to use a distortionless amplifier network and to control or modify the character of the modulation at will, by simple adjustments at the microphone itself.

It has been found that the bad effects of drafts can be avoided without essentially altering the response to sound waves. This was accomplished by the use of properly designed draft shields placed across either end of the short tube containing the glow discharge terminals. The air current resistance of the two shields was made quite different, so that as now used, the instrument is sensitive mainly at one end only. It was found to be undesirable to completely close one end, as this resulted in diminished sensitivity as well as resonance at the natural frequency of the enclosure.

While the ratio of ground tone to signal was greatly reduced by the use of the exploring electrode described above, it was found necessary to determine the source of the noises. There resulted the development of an alloy of low heat conductivity and melting point, to be used for the electrodes. By the proper proportioning of diameter and length of electrodes, and the use of discharge currents of proper value, it proved possible to operate the device continuously over long periods of time, without objectionable ground tone. Furthermore, while the electrodes eventually fail, this occurs after about the same length of service in all cases. It is then a simple matter to design the microphone holders and units so as to be readily replaceable, and to renew them long before they become inoperative.

The development was completed by the working out of a low-current, high-voltage rectifier, with resistance-capacity filters, which permits the discharge to be struck or started by flashover, and maintains its current practically independent of discharge impedance. Units of substantially this construction have been used in the regular broadcasting programs of station *K D K A* for several months.

In conclusion, it may be said that although it is desirable and will doubtless become possible to use a microphone giving a response independent of frequency, this is not done at present. The imperfections of the existing designs of head telephones and loud speakers make it advisable to adjust the modulation, to some extent, so that the received audio signals will be more nearly faithful copies of the originals. This is readily accomplished with the new microphone, so that advantage may be taken of improvements in receiving apparatus as they appear.

PERMISSIBLE TELEPHONES FOR COAL MINES

The Bureau of Mines has just issued Schedule 9A, "Procedure for establishing a list of permissible telephones for use in coal mines," and is prepared at its Pittsburgh experiment station to conduct inspections and tests of telephones designed for use in coal mines. A telephone submitted for permissibility tests shall be so designed and constructed that under no circumstances can its normal operation cause ignition of either dust or gas, or a combination of dust and gas, in the surrounding mine atmospheres. All parts of the telephone shall be adequate for the service for which they are intended.

The construction of permissible telephones shall be especially durable. This requirement shall be applied consistently to all the details of the telephone under test in order that with proper care and maintenance the permissible qualities of the telephone shall remain unimpaired under the severe conditions imposed by mining service.

A thorough inspection of the telephone will be made to determine its adequacy and permissibility. Tests may be made to check the electrical characteristics and constants of the various parts, and to determine the adequacy of the insulation and of other parts or features of the apparatus.

Systems of Single-Phase Regeneration for Use with Series Type Commutator Motors

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Review of the Subject.—*The alternating-current series motor may be adapted to regeneration in a number of important respects more readily than a similar direct-current series motor on account of the following features: (1) The a-c. motor always employs a cross-field winding which prevents armature distortion. (2) A relatively low impressed commutator voltage is used reducing the danger from flashing. (3) With the a-c. system a transformer can be used to obtain desired variation in motor voltage. The advantages of this feature are outlined at length with reference to its effect on regeneration.*

The several schemes of regenerative connections are divided into four classes as follows: (1) Series excitation; (2) self-excitation, or cross excitation; (3) shunt excitation; (4) separate excitation. The first two connections have not been commercially used. A number of fundamental assumptions as to the theory of the single-phase motor are given as a basis for vector diagrams, which are used to analyze the conditions for both motoring and regeneration for the four types of connections. A detailed presentation of the conditions which obtain with these connections is then given by the author.

When using the first connection for regeneration it is necessary with series excitation to reverse the main field with reference to the motoring conditions. With the alternating-current series motor a sudden decrease in the line voltage will not increase the regenerated current as in the case of direct current, but will tend to decrease it. In a like manner an increased speed with any given impressed voltage will also decrease the regenerated current. Objectionable characteristics are: first, a strong tendency to pick up as a direct-current generator with the secondary transformer winding acting as a short circuit; second, a like tendency for low-frequency currents to be set up; third, undesirable speed torque characteristics. These features are cited as the reasons for not seriously considering this type of motor and connection for railway application with regeneration in this country.

The second system employs an extra set of brushes located midway between the normal brushes on the commutator. This system is handicapped by the fact that armatures and also the commutators of the motors must have increased capacity because of the necessity for carrying exciting as well as load currents during regeneration. This is particularly objectionable on account of the space limitations existing in connection with railway application. Another disadvantage is the necessity for extra brushes around the commutator. This method of connection, however, has the advantage of giving a shunt speed torque characteristic and permitting power factor compensation during regeneration.

The third connection using the so-called shunt excitation has the advantage of simplicity and reliability. The chief disadvantage lies in the fact that power factor correction cannot be made during regeneration. It is handicapped to some extent, due to the fact that the same continuous torque between armature and field winding cannot be obtained as was possible with the series connection. In a majority of commercial applications, however, this connection will provide sufficient tractive effort. Only two units are required to obtain regeneration: first, a substantial reactor and, second, a change-over switch for controlling the same.

The fourth system utilizes separate exciters either of the (1) constant speed or (2) variable speed type. Under the constant speed systems, either phase converters or motor generator sets may be used. With the variable speed, either separate axle generators or one of the main motors is used as an exciter. This system, although in general requiring more apparatus for regeneration (hence costing and weighing more) than some of the other systems, is also more flexible. The desired speed torque characteristics can be obtained and, with a constant speed exciter, power factor compensation is available as well as power for driving auxiliary apparatus.

The conclusion is reached that regeneration can be properly and successfully obtained with one or more of the several systems outlined. In the several appendices, explanation is made of the vector diagrams by means of which the author analyzes the conditions for each system of connection.

It has long been known that under certain conditions a motor driving an electric locomotive or car could be converted into a generator and that as such it could be used to exert a braking effect upon the vehicle either for "holding" a train while descending a grade, or for reducing the speed of the train when making a stop.

Numerous articles have appeared in the technical press during the past few years covering various systems of control for use in connection with three-phase, split-phase and direct-current systems of regeneration.

However, practically no mention has been made of systems of regeneration for use with single-phase series type commutator motors.

Probably the reader is better acquainted with the direct-current system at the present time than with any other type. Hence, in the following general discussion the writer will use the d-c. system for comparative purposes.

Presented at the Midwinter Convention of the A. I. E. E., New York, N. Y., February 14-17, 1923.

The Westinghouse Electric & Manufacturing Company tested a regenerative single-phase locomotive on its test track for several months at East Pittsburgh as long ago as 1905, and a few years later a similar system was applied to the Midi locomotive in France.

At that time there was practically no demand whatsoever for regenerative equipments in the commercial field, and the system referred to above was used primarily in connection with a number of important gear tests which were being made at that time. The regenerative feature was utilized to give a relatively cheap and flexible load, two similar locomotives being used during the test, one regenerating while the other motored.

The a-c. series motor lends itself to regeneration in a number of important respects more readily than the corresponding direct-current series type motor. This type of a-c. motor is always provided with a cross-field winding preventing armature distortion, and as it always has a relatively low impressed commutator

voltage, the danger of flashing is practically eliminated.

The a-c. system also has the advantage that the existence of a transformer on the vehicle makes the variation of motor voltage very simple and economical. This, in turn, means that weakened fields at high speeds are not a necessity and that regeneration at practically all speeds down to a standstill can be accomplished with practically any desired field strength. This permits the obtaining of any desired torque with any desired speed, with the armature and field currents adjusted to give the minimum root mean square currents in either member. Thus, in general, it is possible to effect regeneration with a lower root mean square current in the armature and over a greater range in speed than is possible in the case of the direct-current system with its limited and less flexible voltage range; also, due to the presence of the transformer and due to the fact that connections can be completed inductively, as well as conductively, the a-c. series motor lends itself more economically to a larger number of regenerative connections than appears possible with the d-c. system.

The various schemes of regenerative connections available for use with this type of motor can be divided into four distinct classes, or combinations of these classes, depending upon the type of field excitation employed. The four classes can be designated as follows:

1. Series Excitation
2. Self-excitation, or cross excitation.
3. Shunt Excitation.
4. Separate Excitation.

The third and fourth classes have been commercially applied and detailed description of a few of the various forms of connections possible in these two classes will be given in the following pages.

In so far as is known by the writer, no commercial applications of the first and second classes have been made as yet, and only a general discussion of a single form of each of these two classes will be given.

For the sake of clarity it is necessary to give in a brief manner several fundamental assumptions which will act as a basis for the vector diagrams which follow. In all cases it is assumed that the electrical windings are such that:

1. A motoring torque will be exerted when the field flux and armature current of a given machine have a component 180 deg. out of phase with each other.
2. A braking or regenerating torque will be exerted when the field flux and armature current have a component in phase with each other.
3. Power will be taken from the line when the armature current has a component in phase with line voltage.
4. Power will be returned to the line when the armature current has a component 180 deg. out of phase with the line voltage.
5. A lagging armature current will be taken from, or returned to, the line when the resultant wattless current required for the armature circuit is lagging.
6. A leading armature current will be taken from or returned to the line when the resultant wattless current required for the armature circuit is leading.

The following well known fundamental laws will be used frequently and are stated in order that the reader may more easily follow the writer's various presentations.

(1) The sum of the voltages in any closed circuit must be equal to zero, that is, the sum of all the counter voltages must be equal and opposite to the impressed voltage.

(2) When a voltage is applied to a reactance, the current produced will lag 90 deg. behind the impressed voltage. The reactive drop, or counter voltage, produced by this current must be 180 deg. away from the impressed voltage in order to produce a balanced condition, and hence the reactive drop must lag 90 deg. behind the current that produces it.

(3) Likewise, when a voltage is applied to a resistance, the current produced will be in phase with the impressed voltage. The RI drop, or counter volts, produced by this current must be 180 deg. away from

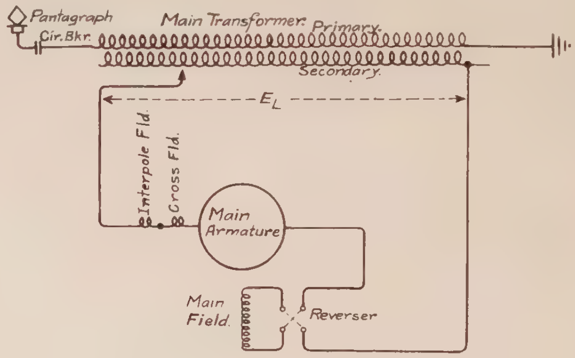

Fig. 1—Series Motor

the impressed voltage in order to produce balance, and hence, it is 180 deg. away from the current.

(4) The counter electromotive force set up, due to a rotating conductor cutting a given flux, will be in phase with the flux cut.

Also, it might be noted that all vector diagrams are arranged so that any leading vector is always drawn counter-clockwise with respect to any lagging vector.

Motoring with Series Excitation[1]

In line with the above the operation of the series motor as a motor assumes the form shown in Fig. 1 which is a schematic of a typical main circuit connection.

The transformer voltage applied across the motor terminals sets up a circulating current in the motor circuit. The motor circuit is inductive and therefore the current lags the impressed voltage. The circulating current thus set up produces a counter voltage equal and opposite to the impressed voltage. At standstill this

1. See Appendix A for detailed Vector Analysis.

counter voltage is composed entirely of the impedance drop around the armature circuit. The impedance drop consists of a resistance and reactance drop. The reactance drop is at right angles to the resistance drop.

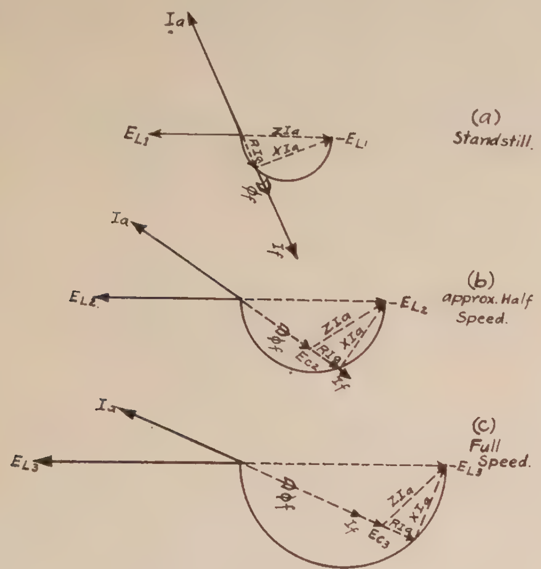

FIG. 2—SERIES MOTOR

The resistance drop is 180 deg. away from the armature current and in phase with the field current.

As the speed of the motor increases a counter electromotive force is set up across the armature which adds directly to the resistance drop in the circuit. Hence at any speed except zero the resultant counter

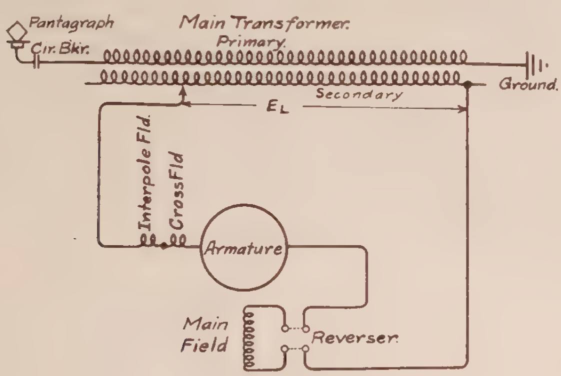

FIG. 3—SERIES GENERATOR

voltage is composed of the counter electromotive force as well as the impedance drop in the armature circuit. As this counter electromotive force grows in value with any given constant impressed voltage the impedance drop and hence the armature current must decrease in value to maintain the proper resultant value of countervoltage. Hence, with a fixed terminal voltage the armature current and consequently the propelling torque, decreases as the speed increases.

Fig. 5 shows the typical shape of the speed torque characteristic obtained with the series connection.

REGENERATION WITH SERIES EXCITATION[2]

In order to regenerate after motoring with the series connection the main field must be reversed. Thus Fig. 3 shows a typical main circuit schematic for this connection. The operation regenerating is similar to the operation motoring except that the field current, and consequently the field flux and resultant torque produced, has been reversed. Thus at standstill the counter voltages set up are exactly the same as in the motoring connections at standstill. However, as the speed increases from standstill the counter electromotive force set up is in the opposite direction and hence opposes the resistance drop but remains at right

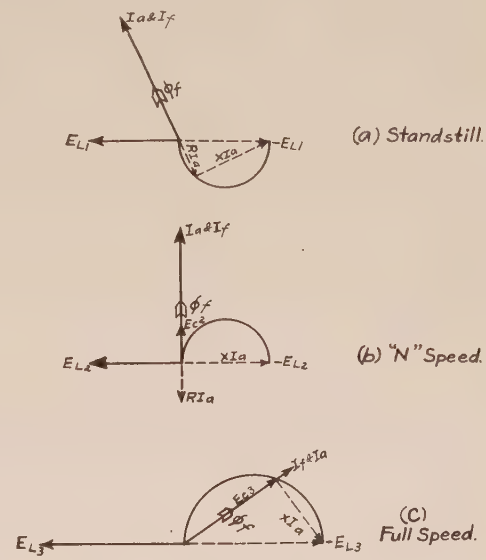

FIG. 4—SERIES GENERATOR

angles to the reactance drop. Thus at some definite speed where the counter electromotive force is just equal and opposite to the $R\,I$ drop the armature current will lag the line voltage by exactly 90 deg. since the only counter voltage available is the reactance drop around the armature circuit.

At this point the generator is supplying its own losses and hence is drawing no power from the line. As the

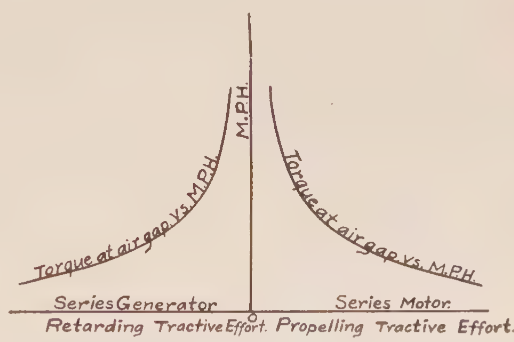

FIG. 5—APPROXIMATE "SPEED T. E." CHARACTERISTIC. SERIES EXCITATION

speed increases above this value the counter electromotive force overbalances the resistance drop and the resultant counter voltage is equal to the vector sum of the reactance drop and the difference between the resistance drop and counter electromotive force and the

2. See appendix B for detailed Vector Analysis.

resultant vector relations are such that power is returned to the line. This can be readily seen if the difference between the counter electromotive force and the resistance drop is considered as a negative resistance drop. The presence of a positive resistance drop indicates the use of power and hence the presence of a negative resistance drop must represent the generation of power.

Thus it is seen that the alternating-current series motor can be made to operate as a series generator merely by reversing the fields. A suddenly decreased line voltage will not increase the regenerated current of the line frequency as in the case of direct current, but will tend to decrease it. Similarly an increased speed with any given impressed voltage will also decrease the regenerated current. While these characteristics would make its use for regeneration possible, other difficulties have to be overcome for a practical solution along these lines.

The system is handicapped by the strong tendency of the generator to pick up as a direct-current generator with the secondary transformer winding serving practically as a short circuit. Even if direct currents are made impossible, as in the case of a repulsion motor, there is a strong tendency for low-frequency currents to be set up, causing trouble. Also the speed torque characteristics obtained with this connection (See Fig. 5) are not the best type for all classes of regenerative service since the torque tends to decrease as the speed increases for any given value of impressed voltage. In view of these difficulties this method of regeneration has so far not been seriously considered for railway application in this country. Undoubtedly, however, due to its simplicity it has possibilities for the future.

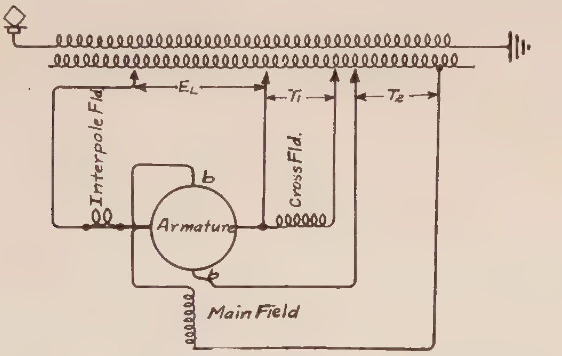

Fig. 6—Cross Field of Self Exciting Generator

Regeneration with Cross-Field or Self-Excitation[3]

A regenerative system of the second kind with the main motors acting as armature (self-excited) generators is shown in Fig. 6. In this system the armature is supplied with an extra set of brushes *b b* which are located around the commutator midway between the normal or motoring set. The cross field is connected across a section of the main transformer. The resultant current and flux set up in the cross field circuit is approximately 90 deg. behind the line voltage since the field circuit is highly inductive. The armature conductors revolving in and cutting the cross-field flux set up by a counter electromotive force across brushes *b b* in phase with the flux cut and hence at right angles and lagging the line voltage.

This voltage is then connected across the main field and sets up a current and flux through the main field

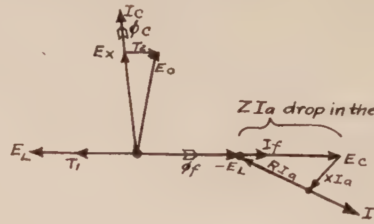

Fig. 7—Cross Field of Self Exciting Generator

approximately 90 deg. behind voltage *b b* or approximately 180 deg. away from the line voltage. The armature conductors revolving in and cutting this main field flux set up a voltage across the normal brushes approximately 180 deg. away from the line voltage. Hence, when these terminals are connected to the transformer the resultant voltage difference will set up a circulating current in the circuit. If the line voltage impressed is greater than generated voltage a motoring torque will be produced and power will be drawn from the line. If the generated voltage exceeds the line voltage a braking torque will be exerted and power will be returned to the line. The small section of transformer voltage in the excitation circuit is introduced in order to neutralize the resistance drops in both the cross field and main field circuits and hence maintain the regenerated voltage exactly 180 deg. behind the line voltage.

Fig. 8 shows the typical shape of the speed torque

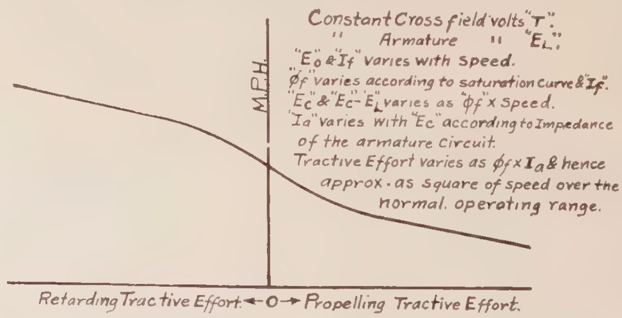

Fig. 8—Approximate Speed-Tractive Effort Characteristic with Cross-Field Excitation System

characteristic obtained with this connection.

This system is handicapped due to the fact that the armatures, and also the commutators of the main motors, have to be increased in capacity because they carry the exciting currents in addition to the load currents. This is quite a serious handicap in view of the space limitations existing for the main motors in con-

3. See appendix C for Vector Analysis.

nection with railway work. Another disadvantage of the system is the necessity of additional brushes around the commutator.

However, such a system is advantageous in so far as it gives a shunt or flat speed-torque characteristic (see Fig. 8) and as it permits of power factor compensation

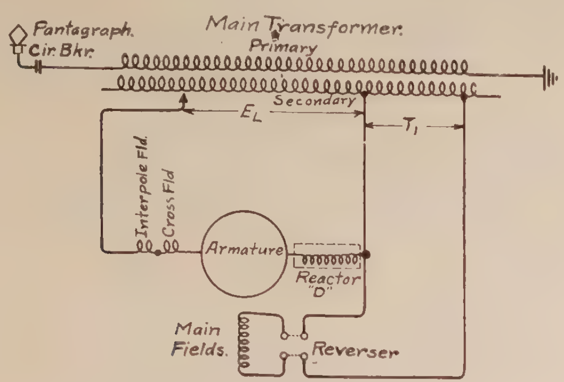

FIG. 9—SHUNT GENERATOR

during regeneration, and possibly during motoring, within certain limits. Hence, it eliminates the necessity of auxiliary rotating apparatus that otherwise might be required to obtain this power factor compensation feature and therefore probably has certain possibilities for the future.

REGENERATION WITH SHUNT EXCITATION[4]

The simplest form for a shunt type regenerative system is shown in Fig. 9. The main fields are connected

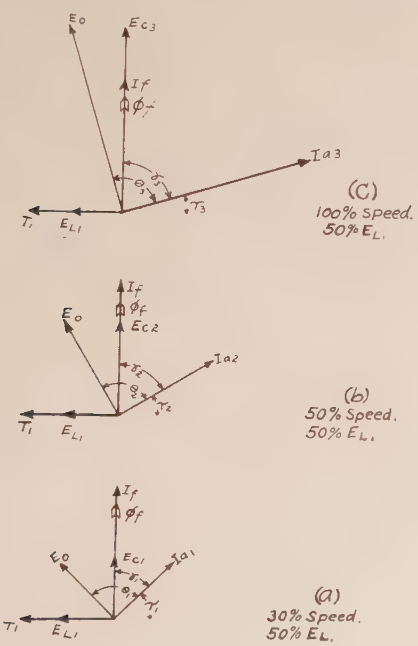

FIG. 10—VARIABLE SPEED—REGENERATING. CONSTANT IMPRESSED ARMATURE VOLTS. SHUNT EXCITATION. CONSTANT IMPRESSED FIELD VOLTS

directly across a section of the main transformer. The resulting field current and flux set up in the circuit lags approximately 90 deg. behind the line voltage. The armature conductors revolving in and cutting the field flux set up a counter electromotive force across the armature circuit in phase with the flux cut and hence approximately 90 deg. behind the line voltage.

The armature is thus connected in series with an

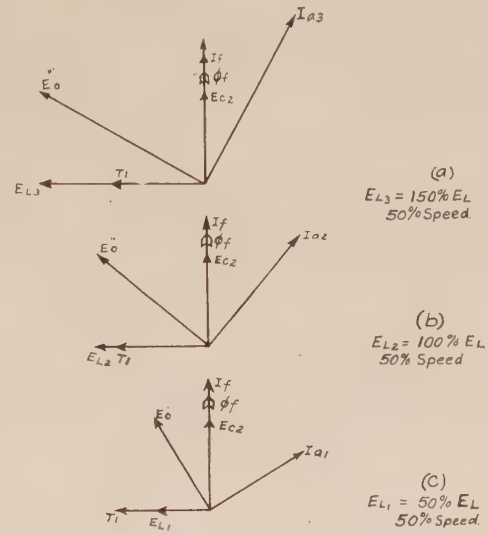

FIG. 11—REGENERATION—CONSTANT SPEED—VARIABLE IMPRESSED ARMATURE VOLTAGE. SHUNT EXCITATION

external reactor and across a section of the main transformer. The vector sum of the counter electromotive force generated in the armature and of the voltage impressed across the armature give a resultant voltage in the armature circuit which lags behind the line voltage by some angle depending upon the relative values of the impressed and generated voltages: This resultant voltage sets up a circulating current in the armature circuit which lags by approximately 90 deg. since

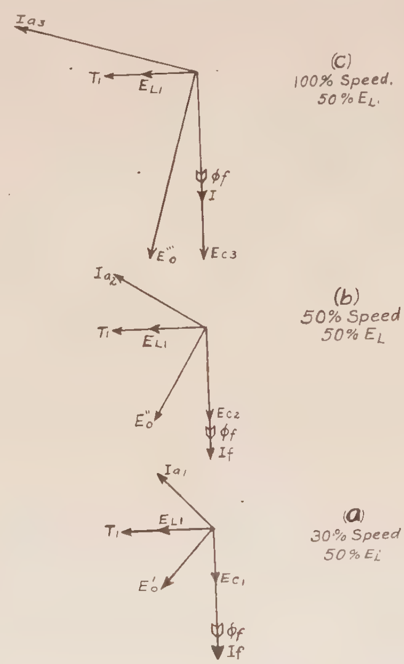

FIG. 12—MOTORING—VARIABLE SPEED—CONSTANT IMPRESSED ARMATURE VOLTS. SHUNT EXCITATION, CONSTANT IMPRESSED FIELD VOLTS.

4. See appendix D for Vector Analysis.

the armature is highly inductive due to the external reactor. Hence, since the field current and flux are also lagging the line voltage the armature current has a component in phase, the field flux, and is therefore exerting a braking torque. Also, due to the fact that the resultant voltage in the armature circuit lags the line voltage and to the fact that the armature current is approximately 90 deg. behind this voltage, the armature current must lag the line voltage by more than 90 deg. hence will have a component 180 deg. away from it. Thus, power will be returned to the line.

If the main fields are reversed in the above connections, the counter electromotive force produced will be

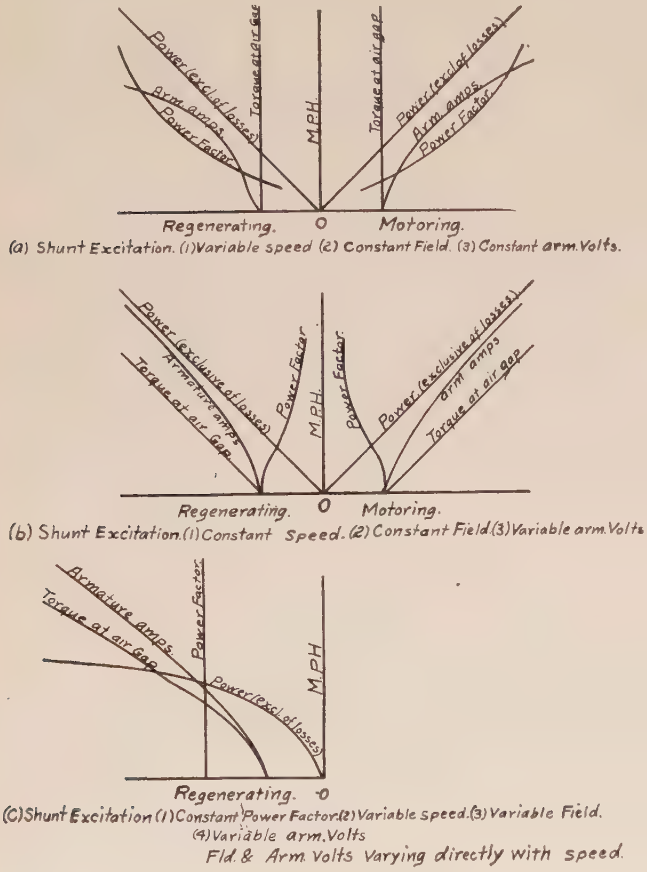

FIG. 13

reversed. This will shift the resultant voltage in the armature circuit by 90 deg. and likewise the armature current.

The resultant voltage will lead the line voltage while the armature current will lag the line voltage, by something less than 90 deg. depending upon the relative values of the line voltage and the counter electromotive force. Hence a motoring torque will be produced and power will be drawn from the line.

Fig. 13 (A, B, and C) gives the typical shape of the different speed torque characteristics for both motoring and regenerating obtainable with this connection.

The chief handicap of this system lies in the fact that it does not permit of power factor correction during the regenerating period and must always draw a resultant wattless component of current from the line for excitation. It is also handicapped to some extent due to the fact that the same continuous torque between the armature and field windings, possible with the series connection, cannot be obtained in the shunt connection due to the phase difference between the armature current and field flux inherent with this connection. However, in practical applications sufficient torque can be developed between the windings

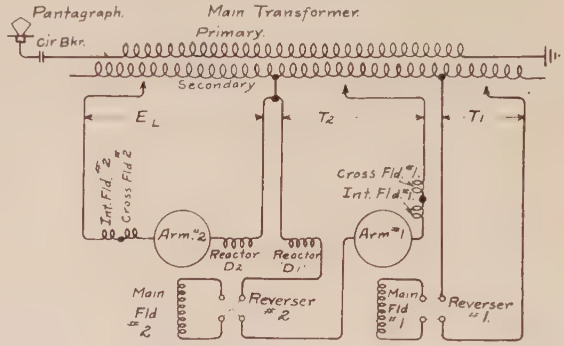

FIG. 14—REGENERATION—MODIFIED SHUNT EXCITATION

such that when added to the losses the resultant retarding effort available will be more than sufficient for holding any train while descending a given grade that can be hauled up the same grade with the series connection. Also, when the obtainable torque is not sufficient for any given application the speed-torque characteristics can be adjusted easily and properly for parallel operation with the airbrakes on the train. Hence, this connection will provide ample tractive efforts for a large majority of the future commercial applications.

The connections and control are simple and reliable. Practically only two units are added to the normal motoring control apparatus, these units consisting of a simple substantial reactor and a simple change-over switch for controlling the reactor. The speed torque

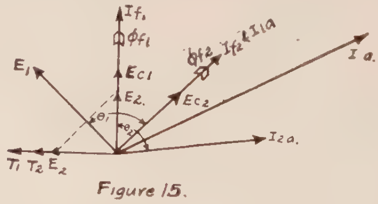

FIG. 15—REGENERATION—MODIFIED SHUNT EXCITATION

characteristics available cover practically the entire range from (1) a vertical curve, that is constant torque at all speeds, (see Fig. 13A) which is ideal for straight deceleration purposes, to (2) a shunt or relatively flat curve, that is increasing torque with increasing speed, (see Fig. 13C) which is the desirable characteristic for use in holding a train at some given desired speed when descending a grade.

Hence, this form lends itself readily to practically any class of service and will undoubtedly be in great demand for future commercial applications.

A modified form of the shunt connection is shown in Fig. 14 and is described in appendix D.

Separate Excitations[5]

The regenerative systems utilizing separate exciters during the regenerating period can be divided into two general classes as follows:

1. Constant Speed Exciter Systems
   (a) Phase Converters
   (b) Motor Generator Sets.
2. Variable Speed Exciters
   (a) Separate Axle Generators.
   (b) Main Motor as an Exciter.

In the following a description will be given of a constant speed exciter system using a phase converter as

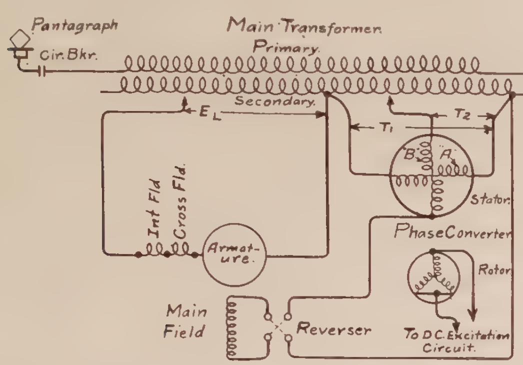

Fig. 16—Regeneration—Constant Speed Exciter System

an exciter. A variable speed exciter system using one of the main motors as an exciter will be described in appendix E.

A constant speed exciter system is shown in Figs. 16 and 17. In this system the phase converter or exciter is essentially a two-phase synchronous or induction motor running on single phase. Hence, a voltage is generated across the second or open phase at right

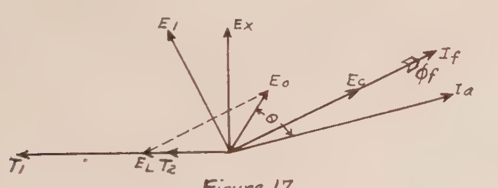

Figure 17.
Regeneration – Constant Speed Exciter System.

Fig. 17—Regeneration—Constant Speed Exciter System

angles to the line voltage impressed across the motoring phase. In most applications of this type a two phase synchronous motor will probably be employed in order that it may be operated as a synchronous condenser during the motoring period for power factor correction. Also, with the use of the direct-current excitation in the rotor the main motor field excitation can be supplied in part if not entirely without drawing it all in the form of wattless lagging current from the line.

The right angle voltage obtained from the generating phase of the phase converter is connected in series with the main field of the traction motor and across a section of the main transformer. The vector sum of these two voltages gives a resultant voltage which sets up a field current and field flux through the field circuit. The resultant field voltage lags the line voltage by some angle depending upon the relative values of transformer voltage and phase converter voltage employed. The resultant field current and field flux lag behind this

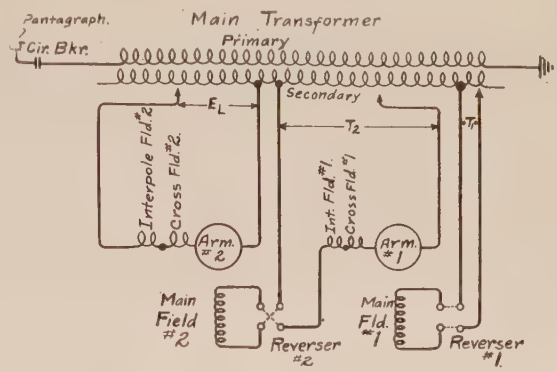

Fig. 18—Regeneration—Variable Speed Exciter System

voltage by 90 deg. since the field circuit is highly inductive, and therefore lags behind the line voltage by more than 90 deg.

The main armature conductors revolving in and cutting this flux set up a counter electromotive force across the armature in phase with the flux cut. The vector sum of this counter electromotive force and of the transformer voltage impressed across the armature gives a resultant voltage which sets up circulating current in the armature circuit. The armature current lags the resultant armature voltage by some angle

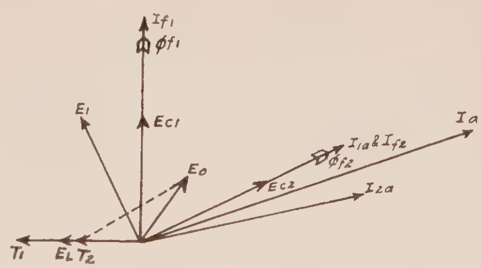

Fig. 19—Regeneration—Variable Speed Exciter System

depending upon the relative values of the resistance and reactance drops through the circuit.

By the proper manipulation of the transformer voltages impressed across the main field and armature circuits (and when desired, the phase converter) the circulating armature current can be given a leading or lagging component 180 degrees away from the line voltage, and at the same time exert a braking torque, or it can be given a leading or lagging component in phase with the line voltage, and at the same time exert a motoring torque. Thus all requirements for regeneration can be fulfilled.

Figure 20A shows three different typical approximate forms of speed torque characteristics, not drawn to

5. See appendix E for Vector Analysis.

scale, obtainable with this system of regeneration. It is possible to obtain a family of curves for practically any desired form of characteristics, by the proper manipulation and choice of the various applied voltages. In fact, with the proper control facilities, it is possible to change from any one family to one or more different families of curves, during the regenerating period. Thus, it is possible to choose the proper form of curve most suitable for each of the various forms of regenerative duty that may be encountered over any given profile. Hence, on grades on which it is necessary to use the air brakes on the train in conjunction with regeneration, in order to hold the train at some desired speed or speeds, a proper family of curves suitable for parallel operation with air brakes can be selected.

As the steepness of the grade decreases and the regenerative torque available is sufficient for holding the train at the desired speed, without the aid of air brakes, a family of curves most suitable for this service

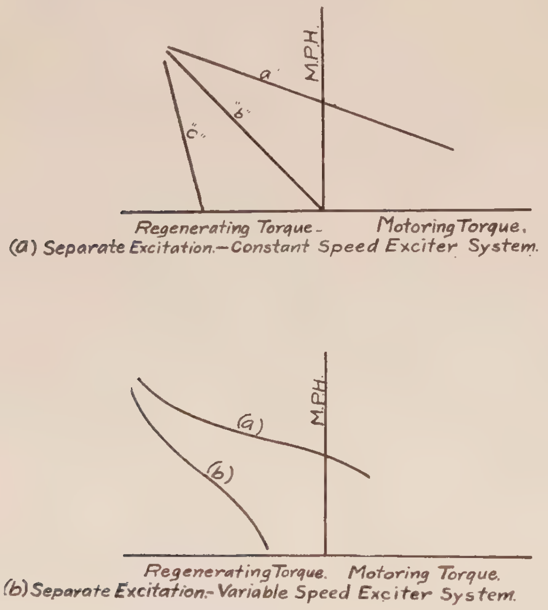

FIG. 20

can be obtained. Then again when it is desired to decelerate the train from some given speed to standstill, the family of curves most suitable for such service can be chosen. Thus this system, although in general requiring more regenerative apparatus, (and hence costing and weighing more), than some of the previously described systems, is also more flexible and hence will also do more than these systems. The control and apparatus required for regeneration are relatively simple and reliable.

The proper speed torque characteristics can be obtained for practically any application and if desired power factor correction during the regenerating period can be easily obtained.

In the constant speed exciter systems the value of torque obtainable is limited by the current capacity of the motor windings only and hence, if desired will give the same continuous torque at the air gap as is obtainable in the series motor connection. Also in this system the constant speed exciter can be utilized for power factor compensation as well as driving auxiliary apparatus during the motoring periods.

Hence, this system, in one or more of its possible forms, will also undoubtedly be used to a large extent in future commercial applications and especially where extremely heavy torque regenerative duty is required.

CONCLUSION

In general, it can be safely stated that probably any future regenerative application that may be desired, can be properly and successfully taken care of with one or more of the various single-phase systems available at the present time.

As a whole the systems are so flexible that the selection of a particular system for any given application can probably be governed in the main by the requirements of the particular application only, and can be chosen to best suit the requirements of that application.

Appendix A

MOTORING WITH SERIES EXCITATION:

The clock diagram for the series motor, operating as a motor, assumes the following simple forms, (see Figs. 1 and 2).

In Fig. 2A, E_{L1} represents the voltage that must be applied across the motor terminals at standstill to set up a current I_a through the motor circuit. The motor circuit is inductive and, therefore, the current lags the impressed volts. The motor is drawing power from the line (equal to the losses in the motor circuit only at standstill), and hence has a component in phase with the line voltage, and since it is exerting a propelling torque, it is 180 degrees away from the field current I_f and field flux ϕ_f.

The counter-voltage at standstill is composed entirely of the impedance drop around the motor circuit, which in turn represents the vectorial sum of the resistance and the reactance drops.

In Fig. 2B, E_{L2} represents the voltage that must be applied across the motor terminals at approximately one-half speed to set up the same current I_a. E_{L2} is greater than E_{L1} due to the fact that the impressed voltage must overcome the back electromotive force of the motor E_{C2}, as well as the impedance drop around the circuit. As E_C grows in value due to speed with any given impressed voltage, the impedance drop and hence the armature current must decrease in value to give the correct vector sum of counter-voltages

In Fig. 2C, E_{L3} represents the voltage that must be applied across the motor terminals at full speed to set up current I_a. E_{L3} is greater than E_{L2}, due to the fact that E_{C3} is greater than E_{C2}.

The power component of current I_a in Fig. 2B and Fig. 2C is greater than the corresponding component in Fig. 2A, due to the fact that the motor is delivering power, hence must draw power from the line.

It should be noted that in both Fig. 2B and 2C the counter electromotive force E_c and the $R\ I$ drop are added directly and their resultant added vectorially to the $X\ I$ drop. When the series connection is utilized for regenerative purposes, it so happens that E_c and the $R\ I$ drop are subtracted from each other and the net resultant thus obtained is then added vectorially to the $X\ I$ drop.

Appendix B

Regeneration with Series Excitation

In order to regenerate with the series connection after motoring, the main fields must first be reversed. The clock diagram for this connection then assumes the simple form shown in Figs. 3 and 4.

E_{L1} represents the voltage that must be applied across the motor terminals at standstill to set up a current I_a through the generator circuit. By referring to Fig. 2A for the series motor, it will be seen that the clock diagram for the series motor at standstill is exactly the same as the clock diagram for the series generator at standstill, except that the field current I_f and field flux ϕ_f have been reversed.

However, as the generator begins to pick up speed as it is propelled down the grade by the weight of the train, the counter electromotive force built up in the armature begins to counteract the resistance drop in the generator circuit until at some speed N, the counter electromotive force (see Fig. 4B), is just equal and opposite to the $R\ I$ drop. At this point the armature current has swung around until it lags the line voltage by exactly 90 deg. This means that the generator is drawing no power from the line whatsoever, and hence at this speed it is supplying its own losses.

As the speed of the train still further increases, the counter electromotive force set up in the armature circuit increases; hence, E_{L3}, Fig. 4C represents the voltage that must be applied across the generator terminals at full speed to set up the current I_a through the armature circuit.

E_{c3} represents the difference between the counter electromotive force generated in the armature circuit at this speed and the resistance drop through the circuit, due to I_a. The vector sum of E_{c3} and $X\ I_a$ is equal and opposite to E_{L3} and, hence a balanced condition exists. The current I_a has a component 180 degrees away from the line voltage, and hence it is delivering power to the trolley. Also, the current I_a is in phase with the field flux ϕ_f, and hence the generator is exerting a braking torque.

It should be noted that as the speed, and consequently the counter electromotive force in the armature circuit increases, the line voltage must also increase in order to maintain the same value of I_a otherwise as the counter electromotive force increases, due to increased speed, the $X\ I$ drop and consequently the current I_a would have to decrease in order to maintain the proper counter-voltage.

Hence, with a fixed terminal voltage, the armature current and consequently the retarding torque, decreases as the speed increases.

Thus, Fig. 5 shows the typical shape of the speed-torque characteristics obtained with the series connection.

Appendix C

Regeneration with Cross-Field or Self-excitation

In this system, the armatures must be supplied with an extra set of exciter brushes as shown in Fig. 6. The operation of this system is as follows: (see Fig. 7).

Assume that with the motors rotating at a certain speed, the cross field circuit is connected to a line voltage T_1. It is evident that a cross field will be set up, the size of which is essentially governed by the number of cross field turns and the voltage impressed upon the cross field. The cross field current I_c and flux ϕ_c lag behind the line voltage E_L by approximately 90 degrees, since the field is highly inductive. This cross field will induce by rotation a voltage E_x between the exciter brushes $b\ b$, which is proportional to and in phase with the cross field, and hence also lags behind the line voltage by approximately 90 degrees.

This voltage is then connected in series with a small section of the main transformer voltage T_2, and the resultant voltage E_o, is connected across the main fields. Since the main field circuit is highly inductive, the field current I_f and flux ϕ_f will lag behind the resultant excitation voltage E_o by approximately 90 deg., and hence will be approximately 180 deg. away from the line voltage T_1. The small section of transformer voltage T_2 in the excitation circuit is introduced in order to counteract the effect of the resistance drops in both the cross field and main field circuits in such a way as to cause the main field flux to lag the line volts by exactly 180 deg. The main field thus set up will, therefore, induce by rotation a voltage E_c across the armature terminals 180 deg. away from the line voltage. The value of this generated electromotive force can easily be adjusted by regulating the voltage impressed upon the cross field circuit, and hence can be made sufficiently in excess of the impressed armature voltage E_L so that a leading regenerated current I_a will be returned to the line. Also, since I_a has a component in phase with ϕ_f, a braking torque will be exerted. Hence, all requirements for regeneration are fulfilled by this arrangement.

Appendix D

Regenerating with Shunt Excitation

The simplest form of connections for a regenerative system of the third kind is shown in Figs. 9 and 10. In this system the main field is connected directly across a section of the transformer voltage T_1 and the armature is connected in series with a current limiting and phase-shifting reactor D, and across a section of the transformer voltage E_L.

The transformer voltage T_1 sets up a current I_f and flux ϕ_f, through the field circuit. I_f and ϕ_f lag behind the line voltage T_1 by approximately 90 deg. The armature conductors revolving in and cutting ϕ_f set up a counter electromotive force E_C across the armature circuit in phase with ϕ_f, and hence approximately 90 deg. behind the line voltage T_1 or E_L. The vector sum of E_C and E_L, or E_0 represents the resultant voltage in the armature circuit which sets up a circulating current I_a through this circuit. The current I_a lags the resultant voltage E_0 by some angle θ, depending upon the relative values of resistance and reactance in the armature circuit, and hence depending in the main upon the value of the external reactor D.

I_a has a component of current in phase with ϕ_f and 180 deg. away from the line voltage E_L. Hence, with this connection a braking torque is exerted and power is returned to the line.

In Figs. 10, 11, 12 and 13 the resistance losses in the various circuits have been neglected for the sake of clarity.

Figs. 10 (A, B and C), show the operation of the generator at three different speeds for a constant field excitation and a constant armature impressed voltage.

From these three diagrams, it is seen that the torque, being equal to the product of the wattless component of I_a and the field flux ϕ_f, remains constant as the speed changes. Likewise, the power returned to the line, being proportional to the product of the watt component of I_a and line voltage E_L, varies directly with the speed, which is as it should be, since a constant torque is being developed at the various speeds.

Fig. 11 (A, B and C), shows the operation of the generator at a constant speed and field strength for three different values of impressed armature voltage.

From these three diagrams it is seen that the torque is directly proportional to the impressed armature voltage, since the wattless component of I_a varies directly with the impressed armature voltage. Likewise, the power returned to the line varies directly with the impressed armature voltage since the watt component of armature current I_a remains constant at the different voltages.

If, in the above connections, (see Fig. 9), the main fields are reversed, a motoring torque will be produced in place of a braking torque. The torque and power characteristics motoring are of the same type as those obtained in the regenerating connection, that is, for any given impressed armature and field voltage, the torque will be constant while the power taken from the line will vary as the speed changes.

Fig. 12 (A, B and C) shows the operation of the shunt motor under these conditions. Likewise, for a constant field strength at a constant speed, the torque produced and the power taken from the line will vary directly with the value of impressed armature voltage.

Fig. 13 (A and B) gives the approximate typical shape of the various characteristic curves, not drawn to scale, for the shunt connection both motoring and regenerating for: (1) constant applied armature and field voltage and variable speed, and (2) constant speed and field strength and variable armature volts.

Fig. 13C gives the typical appearance of the same various characteristic curves, not drawn to scale, for constant power factor and variable speed and automatically controlled field and armature voltage.

Another form of the shunt connection is shown in Figs. 14 and 15. This modified form is only feasible when there are two or more main traction motors on the locomotive or car for use during the regenerating period. This system, as it could be applied to a two-motor proposition, is shown in Fig. 14.

In this system, the main field of motor No. 1 is connected directly across a section of the transformer winding T_1, and the armature is connected in series with the main field of motor No. 2, a reactor D_1, and across a section of the transformer winding T_2. The armature of motor No. 2 is then connected in series with a second reactor D_2 and across a section of the transformer winding E_L.

The transformer voltage T_1 sets up a current I_{f_1} and flux ϕ_{f_1}, through the field circuit of No. 1 motor. I_{f_1} and ϕ_{f_1} lag behind the line voltage T_1 by approximately 90 deg. Number one armature conductors revolving in and cutting ϕ_{f_1}, set up a counter electromotive force E_{C_1} across the armature circuit in phase with ϕ_{f_1}, and hence approximately 90 deg. behind the line voltage T_1 or T_2. The vector sum of E_{C1} and T_2 or E_1 represents the resultant voltage in No. 1 armature circuit which sets up a circulating current I_{1_a} through this circuit.

The current I_{1_a} lags voltage E_1 by some angle θ_1, depending upon the value of external reactor D_1 and sets up a flux ϕ_{f_2} in the main field of motor No. 2, ϕ_{f_a} being in phase with I_{1_a}.

Then the armature conductors of motor No. 2 revolving in and cutting flux ϕ_{f2}, set up a counter electromotive force E_{C_2}, across the armature in phase with ϕ_{f_2}. The vector sum of E_{C_2} and E_L or E_2 represents the resultant voltage in No. 2 armature circuit which sets up a circulating current I_{2_a}. The current I_{2_a} lags the voltage E_2 by some angle θ_2 depending upon the value of reactor D_2.

The vector sum of I_{1_a} and I_{2_a} gives a total resultant armature current I_a, which has a component 180 degrees away from the line voltage, and hence is being returned to the line. Armature current I_{1_a} has a component in phase with ϕ_{f_1} and current I_{2_a} has a component in phase with ϕ_{f_2}. Hence, both the motors are exerting a braking torque and are returning power to the line.

This system can be extended in the same manner for three or more motors, each additional step giving an improvement in the resultant power factor and torque.

The main advantage of these modified forms lies in the fact that the power factor and torque are improved and that the resultant kv-a. required in the external

reactors are decreased by an amount equal to the value of main field reactance utilized in the various armature circuits.

The chief disadvantage lies in the added control complications entailed due to multiplication of the armature circuits.

Appendix E

Regeneration—Separate Excitation

The clock diagram for the regeneration system using a phase converter as an exciter is shown in Figs. 16 and 17.

Referring to Fig. 16, it is seen that a voltage T_1 is applied across the motoring phase A of the phase converter. This induces a voltage E_x across the open or generating phase B. This generating phase voltage E_x is connected in series with a section of the transformer voltage T_2 and the resultant voltage E_1 thus obtained is connected across the main field of the main traction motor. This voltage E_1 sets up a field current I_f and field flux ϕ_f through the field circuit. I_f and ϕ_f lag the voltage E_1 by approximately 90 deg. since the main field is highly inductive.

The armature conductors revolving in and cutting ϕ_f set up a counter electromotive force E_C across the armature circuit in phase with the flux cut. The vector sum of E_C and E_L gives a resultant voltage E_O which sets up a circulating current I_a in the armature circuit. I_a lags E_O by some angle θ depending entirely upon the relative values of the resistance and reactance drops in the armature circuit. I_a has a component of current 180 deg. away from line voltage and hence power is being returned to the line. Also I_a has a component in phase with ϕ_C and hence a braking torque is being exerted. Thus all requirements for regeneration are being fulfilled.

A variable speed exciter system is shown in Figs. 18 and 19. This system is only feasible when there are two or more main motors available for regenerative duty. In this system the main field of No. 1 motor is connected across some section of transformer voltage T_1 and the armature of the same motor is connected in series with the main field of motor No. 2 and across a section of the main transformer T_2. The armature of motor No. 2 is then connected across a section of transformer voltage E_L.

The voltage T_1 sets up a current I_{f_1}, and flux ϕ_{f_1} through the field circuit. The armature conductors of No. 1 motor revolving in and cutting ϕ_{f_1}, set up a counter electromotive force E_{C_1}, across the armature. The vector sum of E_{C_1} and T_2 or E_1 sets up a circulating current I_{1_a} or I_{f_2} and flux ϕ_{f_2} through the field circuit of No. 2 motor. I_a or I_{f_2} and ϕ_{f_2} lag behind E_1 by approximately 90 deg. since the field circuit is highly inductive. The armature conductors of motor No. 2 revolving in and cutting ϕ_{f_2} sets up a counter electromotive force E_{C_2} across No. 2 armature. The vector sum of E_{C_2} and E_L or E_O sets up a circulating current I_{2_a} in this circuit. I_{2_a} lags E_O by some angle θ depending entirely upon the relative values of the resistance and reactance drops in No. 2 armature circuit. The vector sum of I_{1_a} and I_{2_a} or I_a has a component 180 deg. away from line voltage and hence power is being returned to the line. Also I_{1_a} has a component in phase with θ_{f_1} and I_{2_a} has a component in phase with ϕ_{f_2} and hence both motors are exerting a retarding torque. Thus all requirements for regeneration are again fulfilled.

It is interesting to note that the main motor acting as an exciter is not only furnishing the excitation for the other motor but it is also regenerating, that is, it is exerting a braking torque and is returning power to the line. This feature is radically different from the similar type of direct current system. In the direct current system where one of the main motors is used as a generator the motor acting as an exciter returns no power to the line whatsoever and the braking torque exerted is due to the losses in the excitation circuit only. The above feature is due to the fact that the excitation circuit connections, that is, No. 1 motor connections, are essentially the same as those used for straight shunt regeneration, the main field of No. 2 motor serving as the reactor.

Fig. 20B shows the approximate forms of the speed torque characteristics, not drawn to scale, that may be obtained with this type of system.

FOREST RESERVATION AND STREAM FLOW

The last annual report of the National Forest Reservation Commission states that the value of the protection of the forest cover in relation to water power is fully realized in hydroelectric developments which are now being made on streams the upper basins of which are within the purchase units. On the Tallulah and Chattooga Rivers, the headwaters of which are largely protected by the Savannah purchase unit, there have already been installed four units in a water-power development the completion of which calls for seven additional units. The four which have been installed have a generating capacity of 140,000 kilowatts (about 190,000 horse power) and an average annual output of 534,000,000 kilowatt-hours. This large output is secured through storage of storm water by the release of which during periods of low water a nearly uniform output is obtained. The present storage capacity is nearly 8,000,000,000 cubic feet of water. With three additional power units, which are already planned or in construction, the total generating capacity will be increased to 175,000 kilowatts and the total storage capacity will be nearly 9,000,000,000 cubic feet. This storage will be so augmented upon the completion of the entire 11 power units that it is expected that more than 95 per cent of the discharge of these two streams, the largest headwaters of the Savannah River, will be controlled.

The "Blondelion"

A Kinematic Device which Indicates the Performance of a Polyphase Synchronous Generator or Motor[1]

BY VLADIMIR KARAPETOFF
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Review of the Subject.—*There are many engineering problems which can be solved step by step, and there are others which contain two or more inter-dependent unknown quantities and therefore cannot be solved step by step. For example, the diameter of a short transmission shaft, mainly subjected to torsion, can be computed directly for a desired shearing stress; then the pulley can be designed, the belt for the pulley, etc. This is a step-by-step solution.*

On the other hand, let it be required to determine the diameter D and the length L of a cylindrical tank, to hold a given quantity of liquid and to possess a given cooling surface. This problem either requires two simultaneous equations for D and L, or else has to be solved by trials.

The problem of determining theoretically the internal voltage drop and voltage regulation of a given synchronous generator at a given load is one of the second kind, that is, several conditions must be satisfied simultaneously. The problem of predetermining the armature current and the power factor of a given synchronous motor at a given excitation and load is of a similar nature.

The purpose of the kinematic device described in the paper is to enable one to solve these two problems on synchronous machines mechanically, almost without any mathematics and without constructing vector diagrams. The device can be used even by a person who does not know its theory, just as thousands of computers who use the slide rule could not explain the theory of its scales.

A knowledge of the performance characteristics of a synchronous machine is of considerable practical importance, both to its designer and to the user; it has therefore been deemed advisable to simplify and to standardize the procedure so as to make the process as nearly automatic as possible. This should give more time to progressive engineers to think about other problems connected with synchronous machinery, problems which are only partly solved, such as the temperature rise, insulation, transient phenomena, etc.

Two factors in particular complicate the performance of synchronous machines (especially with salient poles), namely the armature reaction and the variable saturation of the magnetic circuit. The effect of the armature reaction is to weaken (or to strengthen) the field flux and also to shift it sidewise. The method of predetermination of voltage regulation given in the A. I. E. E. Standards is admittedly an approximate one, and in designing the Blondelion a more accurate method of taking these two components of the armature reaction into account has been used. This method is known as Blondel's theory of two armature reactions. The curves in Figs. 10 to 13 show a close check between the experimental curves of certain machines and the points read off on the kinematic device. The Blondelion can be readily simplified for use in accordance with the A. I. E. E. method. The variable saturation of the magnetic circuit is taken care of in the device automatically, by means of a proper linkage.

To illustrate the principle upon which the Blondelion is built, let us take again the above-mentioned tank problem and see how a mechanical device could be made for its solution. Let various values of tank diameter D be marked on a certain scale and let the values of tank length L be marked on another scale. Assume that each scale has an index which can slide along it and that these two indexes are kinematically so interconnected that a pointer indicates directly the corresponding volume of the tank on a third scale. The arrangement is somewhat indefinite in that the same volume can be obtained with an infinite number of combinations of values of D and L.

Let now the same indexes be also interconnected by another kinematic linkage, such that another pointer, on a fourth scale, gives directly the area of the cylinder. Here again, an infinite number of combinations of D and L will give the same area. In order, however, to make the third pointer indicate a desired volume, and the fourth pointer simultaneously indicate a desired area, the D and L indexes have to be set at perfectly definite points on their respective scales. These points are readily found by shifting the indexes back and forth. The problem is thus solved, and to use the device one does not even have to know either the cylinder formulas or the nature of the kinematic linkages.

In a synchronous machine there are certain four conditions (explained in the paper), which must be satisfied simultaneously. Therefore, the Blondelion has four independent linkages each of which may assume almost any desired shape. When, however, these linkages are interconnected and certain points and lengths are fixed, the remaining links assume perfectly definite positions, and the desired unknown lengths (which stand for electrical quantities) can be read off directly. In other words, the four linkages represent a system of four simultaneous equations with four unknown quantities, just as the above described tank linkage represents two equations with two unknown quantities. In both cases the solution is entirely automatic, and with properly designed linkages cannot be wrong if the particular setting is right.

Introduction

The Meaning of the Word Blondelion. The device was named for the noted French scientist and engineer, Professor André Blondel, and is based on his theory of two armature reactions in a synchronous machine.

What the Blondelion is. A combination of movable and adjustable bars, linkages, and straight and curved guides (Fig. 1) which can be set to represent, to a certain scale, a vector diagram of voltages, currents, m. m. fs., and fluxes in a synchronous generator or motor of any desired constants. An important feature of the device is a saturation curve of adjustable shape. The parts of the device are kinematically so constrained that when it is set correctly for one load it remains so at any other load, irrespective of a changing excitation, saturation, or terminal voltage of the machine.

The Purposes of the Device. (1) To enable a designer to select the best electrical constants and a no-load

1. The investigation upon which this paper is based was supported by a grant from the Heckscher Foundation for the Advancement of Research, established by August Heckscher at Cornell University.

Presented at the Midwinter Convention of the A. I. E. E., New York, N. Y. February 14-17, 1923.

saturation curve, and to "test" a synchronous generator or motor before it has been actually built. (2) In some applications to take the place of an involved analytical theory; it is often difficult to investigate analytically or numerically the effect of separate factors upon the resultant performance characteristics, especially with considerable saturation. (3) For some purposes to take the place of various proposed circle diagrams which, with a saturated magnetic circuit, are of more than doubtful value and accuracy. (4) To add the judgment of the eye and the skill of the hands to the purely mental ability in selecting the constants of a machine for a desired performance, or in judging the characteristics for assumed constants. (5) To enable an investigator or a student to familiarize himself with a machine as if he had one available for tests.

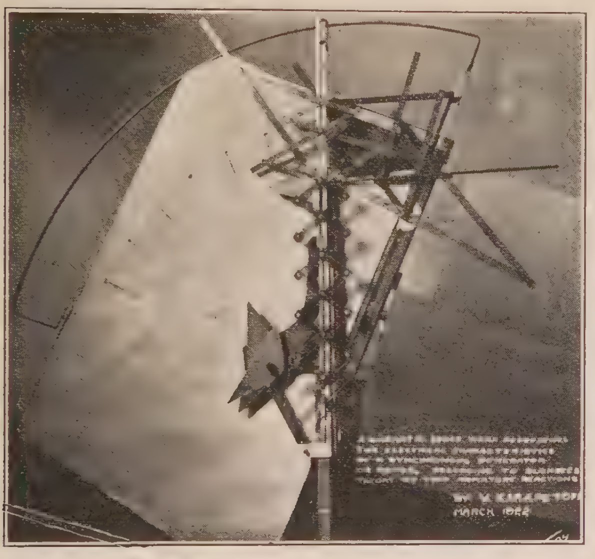

Fig. 1—A General View of the Blondelion

This is of particular importance with large or special machines, for which no facilities may be available for testing under full-load conditions.

The Quantities which Can be Represented on the Blondelion. Current, terminal voltage, internal voltage (or the stator flux), input, output, power factor, internal phase angle, synchronizing torque, and the field current. These quantities may be obtained at a constant applied voltage, at a constant input (or output), or at a constant field excitation, as desired; or else, these factors may be varied in any desired manner.

The Factors Which May be Taken Into Account and Varied Separately at Will in the Blondelion. Per cent armature resistance and reactance; the direct and the transverse armature reaction; the degree of saturation in the magnetic circuit; the field ampere-turns; the copper and core losses; friction and windage.

Other Kinematic Devices. The Blondelion is one of the several kinematic devices developed by the writer, for representing the performance characteristics of various kinds of electrical machinery and lines. The other devices are as follows:

1. A device for imitating the performance of an electromagnetic clutch used in the Owen magnetic car; *Sibley Journal of Engineering,* Jan. 1918, Vol. XXXII, p. 55.

2. The Secomor, a device which imitates the performance of a polyphase series-connected commutator motor; A. I. E. E. Trans., 1918, Part 1, Vol. XXXVII, p. 329.

3. The Indumor, a device which imitates the performance of a polyphase induction motor; also its modification, the Secomor, which represents the performance of a shunt-connected polyphase commutator motor; A. I. E. E. Journal, 1922, Vol. XLI, p. 107.

4. The Heavisidion, a device which represents the operating characteristics of an elecrtical transmission line with distributed capacitance and leakage A. I. E. E. Journal, 1923, Vol. XLII, p. 127.

5. The C. P. S'er (named for Dr. C. P. Steinmetz), a device for the automatic addition of impedances in series and admittances in parallel. (in preparation).

6. An Intergraph based on the author's parallel double-tongs, for a mechanical integration or differention of a given curve. This device finds its usefulness in problems of hunting of electrical machinery, flywheel design, ship stability, etc. *Optical Society of America and Review of Scientific Instruments, Journal* 1922, Vol. VI, p. 978.[1]

Limits of Rating and Output. Like any other graphical device, the Blondelion requires certain scales to be chosen for each particular problem. A convenient scale has to be selected for volts, another for armature amperes, still another for the field current, etc. The device can therefore represent the performance of a small machine as well as of one whose output runs into tens of thousands of kilowatts; of a 110-volt machine as well as of one wound for 22,000 volts. As in any graphical device, there are some limitations due to a finite length of the bars and to an interference of the links in certain positions. With one setting the device can be made to give an accurate performance for all values of practical interest, say between one-quarter full-load and twice the full-load, and between 60 and 100 per cent power factor. For points beyond these limits some bars may have to be replaced or a different scale selected.

B. General Description of the Blondelion

The first complete Blondelion, shown in Fig. 1, was built in the writer's experimental shop, in Cornell University, during the winter of 1921-22. The same device is represented by a single-line diagram in Fig. 2; the construction details are shown in Figs. 6 to 9. Most parts are made of flat steel bars, or of celluloid bars, not over two centimeters wide and a few milli-

1. For a description of the parallel double tongs see the *American Machinist,* 1921, Vol. 55, p. 1050.

meters thick. Some bars are of constant lengths, others are of adjustable useful lengths, holes being drilled every few millimeters. Most bars are connected to each other by means of pivot joints. Some points are constrained to move along straight or curved guides.

The device is assembled on a table provided with a groove XX (Fig. 2.) A stationary rail $H\,H$ supports the free end of the main bar $O\,T$ which can turn about O as a center. The bar $O\,T$ is provided with a longitudinal slot which serves as a guide for the slide $F\,F$, roller S, linkage $O\,Q\,G$, T-square $t\,t$, and the linkage $G\,K\,C$. By means of the T square $t\,t$, the bar $p\,p'$ is made to remain at right angles to the bar $O\,T$. The proportional dividers $A\,N\,C\,D$ are guided by $p\,p'$ at D.

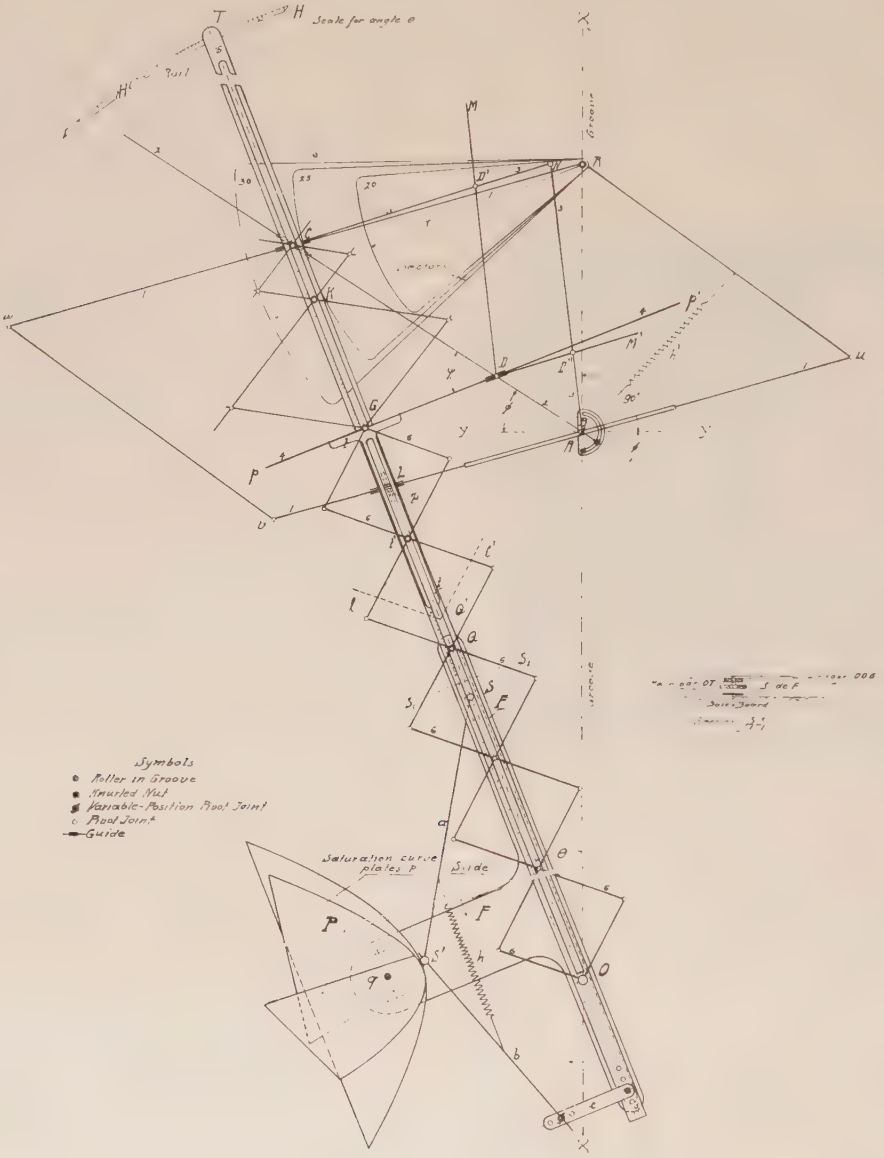

Fig. 2— A Single-Line Diagram of the Blondelion

Different bars are placed in different horizontal planes to enable them to cross each other without interference. In Fig. 2 the bars nearest to the table are marked 1, those immediately above them are marked 2, etc. The particular sequence selected is not essential since the device is intended to represent a vector diagram in a plane.

A detailed description of the functions of the different parts of the Blondelion is given below, in connection with its theory. It suffices to state here that the device is set for chosen design constants and for a desired shape of the no-load saturation curve. The setting consists (a) in the selection of a suitable scale for volts, (b) in the selection and adjustment of a proper curve plate (or plates) to correspond to the desired saturation curve and (c) in the adjustment of the lengths of a few bars. The Blondelion then represents vectorially the following four simultaneous relations which together characterize the machine:

(a) The voltage drop in the armature winding.

(b) The component induced e. m. fs.

(c) The main magnetic circuit, modified by the armature reaction.

(d) The relationship between the flux, the net induced e. m. f., and the resultant m. m. f.

After having been properly set and connected to represent the above relations, the aggregate of the linkages becomes a kinematic system of a limited number of degrees of freedom. Thus for example, if the field current and the power factor of the load are kept constant, the parts of the device can be moved only in such a way as to represent variations of the terminal voltage with the armature current; the device then possesses only *one degree of freedom.* If the terminal voltage is kept constant, it is possible to vary the energy component of the current independently, and its reactive component by varying the field excitation; the device then is a system with *two degrees of freedom*; etc.

Having set the device for the desired operating conditions of the machine, certain of its parts can be shifted in the grooves or along the guides, thus causing all the other members to assume new positions. At any position, readings can be taken of the voltage, current, power factor (or phase angle), field excitation, output, deviation of the field structure from its no-load position, etc. In other words, at least as many characteristic quantities can be read directly as with an actual load or brake test, with an additional advantage of having the currents and the voltages directly and automatically combined into a vector diagram.

Lengths are measured on the centimeter scales marked along the bars and the grooves, and the phase angles are read by means of protractors, or with a sighting goniometer (see the author's paper on the Indumor, mentioned above). Or else, angles may be computed from the measured projections of the vectors.

C. The Performance Diagram of a Polyphase Synchronous Generator

The vector diagram in Fig. 3 represents the terminal voltage, the current, and the induced electromotive forces in a polyphase synchronous generator with salient poles, on a partly inductive load. The relations are shown from the point of view of Blondel's theory of the direct and transverse armature reactions. The notation is that used in the author's "Magnetic Circuit," Chap. 8, to which the reader is referred for explanations and proofs. One phase only is represented in the diagram; e is the terminal voltage; i is the armature current; $i\,r$ is the ohmic drop and $i\,x$ is the reactive drop in the armature, per phase. E is the resultant induced voltage considered as a geometric sum of the voltages E_n and E_t induced by the real and fictitious poles of the machine respectively. The current i is shown lagging behind the terminal voltage e by an angle ϕ. The ohmic drop $i\,r$ is in phase and the inductive drop $i\,x$ is in quadrature with the current. The induced voltage E is also the resultant of e, $i\,r$, and $i\,x$, and is a measure of the total stator flux which approximately determines the core loss.

In accordance with the theory explained on p. 151 of the "Magnetic Circuit," the armature current i is resolved into two components, $i_d = i$ Sin ψ and $i_t =$ Cos ψ. The component i_d is such that the m. m. f. wave due to it (in all the three phases) glides along the air gap in a direct juxtaposition to the field m. m. f., weakening or strengthening the latter. This part of the armature m. m. f. is known as the *direct armature reaction*; hence the subscript d. The components i_t in the three phases form an m. m. f. also gliding along the air gap, but with its maxima and minima midway between the main poles. This is known as the *transverse armature reaction*, and the corresponding symbols are provided with the subscript t.

The direct armature reaction is arithmetically subtracted from (or added to) the field excitation, and the resultant m. m. f. produces the useful flux which induces in the armature winding the e. m. f. E_n; the subscript n stands for the word "net." The transverse armature reaction gives rise to a flux which induces in the armature winding the e. m. f. E_t. Since the two

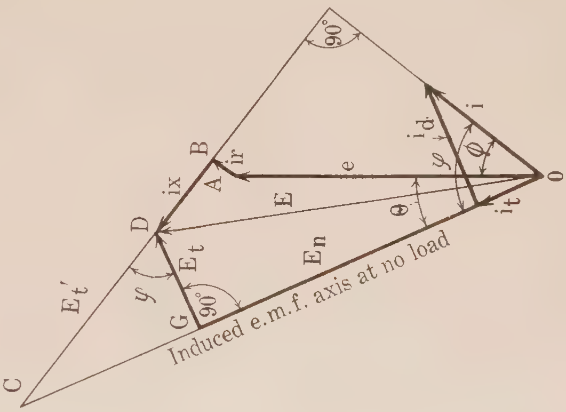

Fig. 3—The Vector Diagram of a Synchronous Generator

revolving fluxes are in *space* quadratures, the corresponding e. m. fs. are in *time* quadrature. When the machine is acting as a generator and the current is lagging, E_t lags behind E_n. The transverse m. m. f. and its flux being proportional to the component i Cos ψ of the current, it is convenient to extend $B\,D$ to its intersection with $O\,G$ at C. The angle at D being equal to ψ, same as at O, the triangle $C\,D\,G$ is similar to the current triangle. Therefore, $C\,D$ is proportional to the total current i on the same scale on which $D\,G$ is proportional to its component i_t. For the value of the coefficient of proportionality see the "Magnetic Circuit," p. 156, eq. (84), in which $E_t' = C\,D$.

The diagram in Fig. 4, on which the Blondelion is based, is identical with that in Fig. 3, except that the ohmic drop $i\,r$ is neglected, since in usual 25- and 60-cycle alternators of medium and large size its value is small as compared to $i\,x$. This simplifies the construc-

tion of the device, although $i\,r$ could be taken into account, as in the Indumor. The direction of the terminal voltage, e, is taken along the X-axis. The current vector is omitted, since $B\,D$, $D\,C$, and $B\,C$ are proportional to the current, and any of the three may be taken as a measure thereof. In interpreting the diagram, it must be remembered that $B\,D$, considered as the armature current, is turned ahead by 90 degrees, while as the reactive drop it is in its true phase position. The same remark applies to $D\,C$.

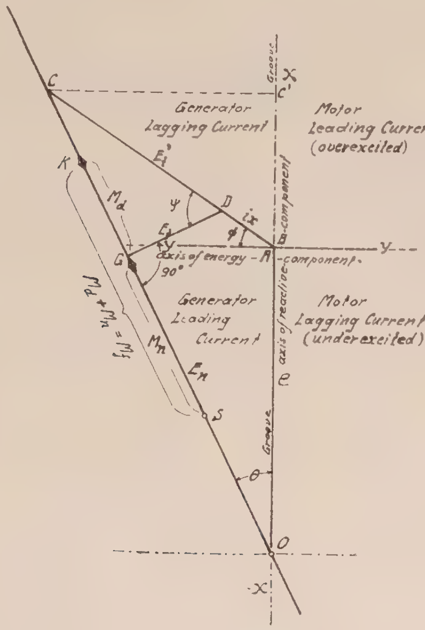

Fig. 4—An Alternator Diagram as Represented by the Blondelion

The direct armature reaction, being proportional to i Sin ψ, is also proportional to $G\,C$, since $C\,D$ is proportional to the current, and the angle at D is equal to ψ. However, the coefficient of proportionality of the direct armature reaction (Magnetic Circuit, p. 153, eq. 79), is different from that of the transverse reaction; moreover, the direct reaction, M_d, is expressed in ampere-turns, while the effect of the transverse reaction is taken into account by means of the e. m. f. E_t. For these reasons the direct armature reaction is represented not by $G\,C$, but by $G\,K = M_d$. In the Blondelion, the ratio of $G\,C$ to $G\,K$ may be adjusted at will and then kept constant for any setting corresponding to a given machine.

Let furthermore $S\,G = M_n$ represent the net field excitation necessary for inducing the net e. m. f. $O\,G = E_n$. Then the actual number of ampere-turns, M_f, on the field poles must be equal to the sum of M_n and M_d, since the amount M_d is counterbalanced by the direct armature reaction. The values of M_n, M_f and E_n are taken from the no-load saturation curve, but this curve should be corrected for a greater magnetic leakage at full load; this is actually done by careful designers.

We thus see that the various linkages of the Blondelion must be such that with any setting for a given machine, the following four vectorial relationships be fulfilled:

(a) The geometric sum of the terminal voltage e and the reactive drop $i\,x$ must be equal to the total induced e. m. f. $O\,D = E$.

(b) The sum of the induced e. m. fs. E_n and E_t must be equal to the same induced voltage $O\,D = E$. Besides, E_n and E_t must remain in quadrature with each other, and both must have the values imposed by the field excitation and the armature reaction.

(c) The length $D\,C$ must remain proportional to $B\,D$ and be in line with it, both $B\,D$ and $D\,C$ being proportional to the armature current. $G\,K$ must remain proportional to $G\,C$.

(d) The field excitation M_f, corrected for the effect of the direct armature reaction M_d, must be equal to the net excitation M_n which corresponds to E_n on the no-load saturation curve of the machine. The proper relationship between M_n and E_n must be preserved at all loads, and the effect of a variable saturation correctly taken into account.

D. The Kinematic Details of the Blondelion

Having established the necessary relationships which must exist between the vector diagram in Fig. 4 and the linkages in Fig. 2, it remains to show how the various points of the device are constrained to move along certain paths in order that the above-mentioned four conditions remain fulfilled with any desired setting.

I. The Saturation Device

The saturation device (lower part of Figs. 1 and 2) is that component mechanism of the Blondelion which permits to vary simultaneously the induced voltage E_n and the corresponding field current, or the m. m. f.

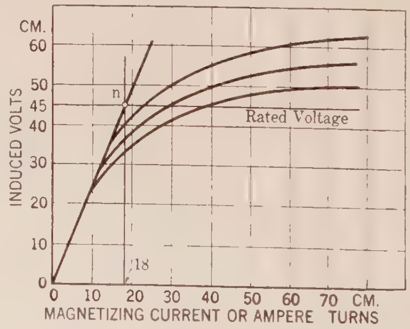

Fig. 5—No-Load Saturation Curves of Different Machines Replotted to a Standard Scale

M_f, in accordance with a chosen no-load saturation curve of the machine (Fig. 5). In order to simplify the construction and the use of the device, it is convenient to replot to a standard scale a given no-load saturation curve, to be used in the Blondelion. In the particular instrument shown in Figs. 1 and 2, the induced voltage E_n is represented by the length $O\,G$ of five rhombi, while the corresponding excitation, on the straight part of the saturation curve, is represented by that of the

two rhombi, $Q\,G$. Therefore, the no-load saturation curve must be plotted to such a scale that on its straight part, when the field excitation is represented by say a cm., the corresponding voltage is represented by (5/2) a cm. Moreover, with the chosen dimensions of the device, it is convenient to select such a voltage scale that, for the rated voltage, $O\,G$ is equal to about 45 cm.

In Fig. 5 the point n corresponds to a rated voltage of 45 cm. and to a field m. m. f. of (5/2) 45 = 18 cm. With these assumptions, the extended straight parts of all no-load saturation curves pass through the same point n, and the only difference lies in the upper curved parts of these curves. An actual study of many saturation curves showed that the differences in the upper parts, when re-plotted to a standard scale, are comparatively small, so that a setting within wide limits is possible with only three curve plates.

The saturation device (Fig. 2) is mounted on the slotted bar $O\,T$, pivoted at O. A rhombic articulated lattice $O\,G$ may be expanded and contracted along the bar $O\,T$, and the length $O\,G$ represents the net induced e. m. f. E_n (Figs. 3 and 4). When $O\,G = 45$ cm., $G\,Q = (2/5) \times 45 = 18$ cm. Therefore, with this particular setting, $G\,Q$ represents the excitation corresponding to point n in Fig. 5. In other words, as long as the machine operates on the straight part of the saturation curve, the above described linkage, contracted or expanded, gives the correct relationship between the induced voltage and the field current.

In order to take care properly and automatically of the upper curved part of the no-load saturation curve, the linkage $a\,b\,c$ is added, with rollers S and S'. The roller S is guided by the bar $O\,T$, the roller S' runs along the curved plates P. A tension spring h, between a and b, causes the roller S' to press against the plates P. These plates are supported by the slide $F\,F$ which is fastened to the rhombic linkage at Q and can move along the bar $O\,T$ in ball bearings. In order to represent synchronous machines with low, medium, and high saturation, a set of three curved plates is provided. Parts of these plates are combined by trials to form a desired saturation curve. Any plate can be turned into a desired position and fastened with the set screw q. Furthermore, the point of attachment and the length of the link c are adjustable. Actual experience shows that by properly setting the plates, by using the right portions of their edges, and by correctly adjusting the link c, any reasonable saturation curve can be duplicated with sufficient accuracy.

The excitation corresponding to the voltage $O\,G$ on the upper curved part of the no-load saturation curve is no more represented by the length $G\,Q$, but by $G\,S$. The arrangement is such that when $O\,G$ is short, points Q and S coincide and move together, giving the straight part of the saturation curve. As $O\,G$ increases in length, the slide $F\,F$, by virtue of its connection at Q, is forced upward. Hence, the curved plates move upwards, allowing the roller S' to move to the left and to change the position of S. The shape of the curves is such that the distance $S\,G$ varies as the exciting current, or as the ampere-turns M_n, when $O\,G$ varies as the induced voltage E_n.

In some applications it may be desirable to make the field excitation scale independent of the voltage scale, and not to use always the same point n (Fig. 5). This can be done by adding a separate adjustable linkage $l\,Q'\,l'$ (Fig. 2) which can be attached to the main rhombic linkage at any desired place, by means of tapped holes and screws, as in Fig. 6. The plate $F\,F$ is then attached to Q', instead of Q, and the roller S must coincide with Q' on the straight portion of the no-load saturation curve.

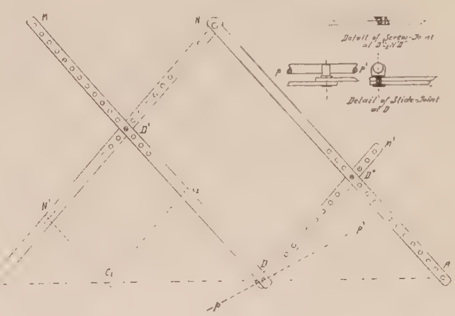

Fig. 6—Proportional Dividers for the Reactance Drop and for the Transverse Armature Reaction

II. The Proportional Dividers for the Reactance Drop

In Figs. 2, 3, and 4 both $B\,D$ and $D\,C$ are proportional to the armature current, and therefore, for a given machine, their ratio must be kept constant for all values of the current, that is, for all possible settings of the device. The proportional dividers used for this purpose are shown in Fig. 6, the corresponding points being denoted by the same letters as in Fig. 2. The dividers consist of four members; the bars $A\,N$, $C\,N$, and $D\,M$ are of the same length; the bar $D\,M$ is of about half their length. An extra linkage, $C_2\,C_1\,N'$ may be added if so desired, to have the current represented by a separate vector $A\,C_1$. However, the distances $A\,D$, $A\,C$ and $D\,C$ are all proportional to the current, so that it is only a matter of the scale.

By opening or closing the dividers, the distance $A\,C$ may be varied at will, and the distances $A\,D$ and $D\,C$ always remain proportional to it. To enable the ratio of $A\,D$ to $D\,C$ to be set in accordance with the constants of the machine, holes are drilled and tapped in all the bars, as shown in the detail sketch. Countersunk machine screws are used for fastening the bars together at the desired points; these screws do not prevent free rotation of the bars relatively to each other. The point D is provided with a pivoted guide shown in the detail sketch; the cylindrical bar $p\,p'$ (Figs. 2 and 7) can move freely through this guide. The purpose of the bar $p\,p'$ is to complete the vector polygon $O\,B\,D\,G$ (Fig. 4).

The bars $A\,N$ and $C\,N$ must be long enough to allow the dividers to open for the highest desired value of the armature current. The shorter bar and the holes along the bars must allow of a setting for the highest percentage of reactance drop and of transverse armature reaction that may be encountered under the extreme practical conditions. To illustrate, let the length of the vector $O\,A$ of the rated terminal voltage be 45 cm., and let, for a machine of normal characteristics, the sum of the reactive drop $i\,x$ and of the voltage E_t' (Figs. 3 and 4), at the rated armature current, be say 50 per cent of the terminal voltage. Then, if performance characteristics are desired up to twice the full-load current, the length $A\,C$, with the dividers fully opened, should be not less than 45 cm. The lengths of the bars in the above described dividers allow an opening of 70 cm., so that the device can be used either for a heavier overload or for machines of much poorer voltage regulation. For a special machine, or under some extreme conditions, for example for a reactive self-exciting machine without d-c. excitation, an entirely different voltage scale may have to be selected.

If it is desired to take the ohmic drop into consideration, the generalized proportional dividers may be used, similar to those described in the author's paper on the Indumor (see reference above).

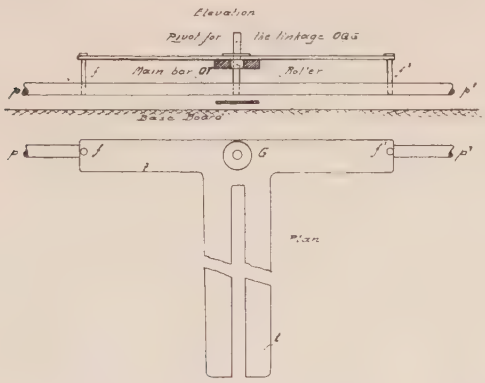

Fig. 7—*T*-Square for the Direct and the Transverse Armature Reaction

III. The Proportional Dividers for Direct Armature Reaction

In the description of Fig. 4 it has been explained that the direct armature reaction, $M_d = G\,K$, is proportional to the length $G\,C$. In order to realize this relationship in the Blondelion, rhombic proportional dividers are used, with centers at C, K, and G (Fig. 2). These dividers are independent of the rhombic linkage $O\,G$. In their general construction the dividers $G\,K\,C$ are similar to those shown in Fig. 6. The sides of one of the rhombi are provided with holes (Fig. 1) for adjusting the ratio of $G\,C$ to $G\,K$ for a given machine. The total field excitation, M_f, is proportional to the length between the points S and K, and is measured on a centimeter scale placed between these points. When the performance is desired at a constant field current, a link of constant length may be placed between these points.

IV. The Slotted T-square for Keeping the Direct and the Transverse Reaction at Right Angles to Each other

It has been explained in the description of Figs. 3 and 4 that with any setting of the device the vectors $O\,C$ and $G\,D$ must remain perpendicular to each other. This is obtained by means of the T-square $t\,t$ (Figs. 2 and 7) fastened to the round rod $p\,p'$. The T-square is made of sheet brass. Its shorter arm is pivoted at G and its longer arm is guided in the direction $O\,G$ by the roller pin t' of the rhombic linkage $O\,G$. The T-square and the rod $p\,p'$ are fastened together by means of pins f and f' and the pivot G (Fig. 7). At D (Fig. 2) the rod $p\,p'$ passes through a guide, shown in the detail sketch in Fig. 6. The T-square is shown in Fig. 1 with the right-hand side of its shorter arm cut off. The T-square and the bar $p\,p'$ are in different planes above and below the main bar $O\,T$, so as to allow the slide at D to move over the whole length of the bar $p\,p'$ without interference with the pivot G or with the pins f and f'. The main bar $O\,T$ can therefore cross all the other bars.

V. The Armature Current, the Terminal Voltage, and the Phase Angle

As is explained above, the magnitude of the armature current is proportional to the opening of the proportional dividers $A\,C$ (Figs. 2 and 6). The length $A\,C$ can be measured on a centimeter scale (Fig. 8) pivoted at A and constrained to slide in the sleeve g at C. The A end of the scale is made into an indicating pointer by means of which the phase angle (or the power factor) of the current can be read off directly on the protractor. Since in the Blondelion the current vector is turned by 90 deg. with respect to its true position, the terminal voltage and the current are in phase, when the bar $A\,C$ is prependicular to the axis $X\,X$. For this reason 0 deg. and 100 per cent power factor are marked in the center of the protractor.

The terminal voltage $e = O\,A$ (Fig. 4) is measured on the centimeter scale $k\,k$ (Fig. 8) which forms one of the two guides for the center A, with its horizontal roller r'. The center line of the groove $X\,X$ represents the direction of e. The groove is cut in the drafting board or the table on which the whole device is mounted. The distance is measured from O to one of the edges of the protractor and a correction is made for its radius.

When it is desired to investigate the performance of a machine at a constant armature current, the set-screw j is tightened, thus fixing the length $A\,C$. To test the performance of the machine at a constant terminal voltage, the set-screw j' is tightened. To find the characteristics at a constant power factor the set-screw j'' is fastened.

VI. The Load Device

The electrical output of a generator, per phase, is equal to the terminal voltage $O\,A$ (Fig. 9) multiplied by the component $C\,C'$ of the current $A\,C$. It must be remembered that in the Blondelion the current vector is turned by 90 deg. with respect to its true phase position, so that $C\,C'$ is the energy component of the current, in phase with the voltage $O\,A$. For any setting of the device, the distance from point C to the center $X\,X$ of the groove can be readily measured and thus the output computed. The same applies to the electrical input of a synchronous motor.

In some uses of the Blondelion it may be desirable to read the electric power directly, on a suitable scale, and for this purpose the arrangement shown in Fig. 9 has been devised. It consists of the articulated parallelogram $u\,v\,w\,R$ and of a celluloid sector $R\,R'$, of shown in the detail sketch in Fig. 8. The sector $R\,R'$ is forced to remain in contact with the side of the bar $O\,T$ by means of the tension spring h' shown between the bars $u\,v$ and $w\,R$. With changes in the setting, the sector rolls on $O\,C$. The power scale depends upon the radius r of the sector.

The theory of this linkage is as follows: The power, being equal to $O\,A \times C\,C'$, is proportional to the area of the triangle $O\,A\,C$. But the same area is equal to $O\,C \times A\,A'$, where $A\,A'$ is the altitude of the triangle with respect to the base $O\,C$. Since $u\,v$ is always parallel to $R\,w$, the triangles $O\,A\,L$ and $O\,R\,C$ are similar to each other, so that $O\,C/r = O\,L/A\,A'$. Hence,

$$\text{Power} = k_e\,k_i\,O\,A \times C\,C' = k_e\,k_i\,O\,C \times A\,A'$$
$$= k_e\,k_i\,.\ r\,.\,O\,L.$$

In this expression k_e is the voltage scale coefficient, that is, volts (or kilovolts) per cm.; k_i is the scale

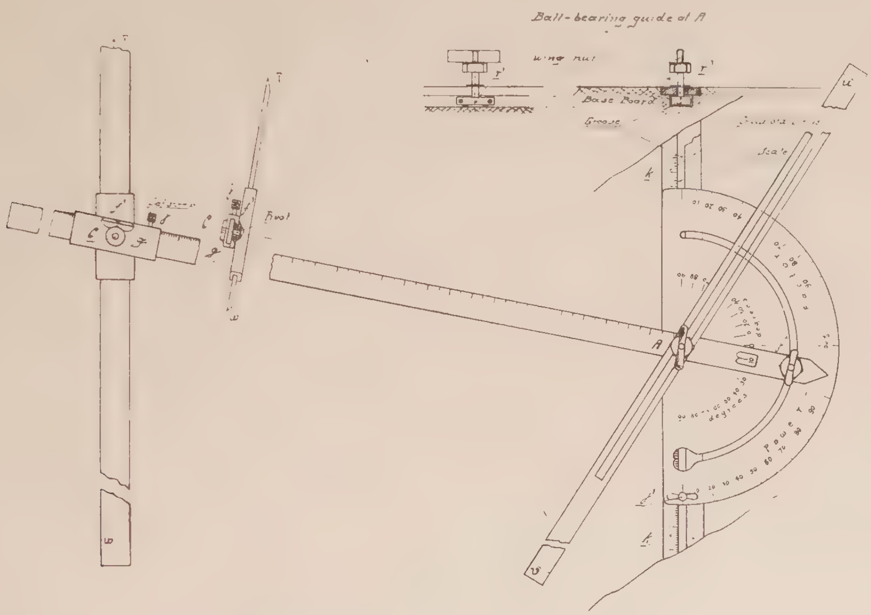

Fig. 8—The Protractor and the Scale Bar $A\,C$

radius r. The parallelogram is constrained as follows: At R there is a vertical pin with a horizontal roller which can move along the groove $X\,X$. The construction is similar to that of the ball bearing guide at A, shown in the detail sketch in Fig. 8. The bar $u\,v$ has a slot which forces the center line of $u\,v$ always to pass through point A (Fig. 8). The bar $w\,R$ can slide through a guide at C. It is proved below that with any setting of the device the power is proportional to the length $O\,L$ on the main bar $O\,T$.

If it is desired to investigate the performance of a generator at a constant output (or that of a motor at a constant input) the double slide at L is fastened to the bar $O\,T$ by means of the set screw z. This causes the length $O\,L$ to remain constant, but does not otherwise hamper the motion of the parallelogram, since the two slides at L can turn with respect to each other. The construction is similar to the double slide at point C, coefficient of the armature current, that is, amperes per cm. Both coefficients are constant, and so is the radius r, with a given sector. Hence, the power is proportional to the length $O\,L$.

As an example, let the Blondelion be set for a three-phase, Y-connected alternator, the current scale being $k_i = 50$ amp./cm., and the e. m. f. scale $k_e = 100$ volt/cm., the voltage being measured per phase of Y. Let the radius of the sector be $r = 25$ cm. To find the power scale, we compute the length $O\,L$ corresponding to an output of say 1000 kw. per phase. We have

$$1000 \times 1000 = 100 \times 50 \times 25 \times O\,L,$$

from which $O\,L = 8$ cm. Hence, the power scale is $1000/8 = 125$ kw. per cm. The scale for the total power for the three phases is 375 kw. per cm.

It is convenient to have several sectors of different radii (Fig. 2) since each sector gives the best results only within a certain range of settings.

VII. The Generator and the Motor Range

So far the parts and the setting of the Blondelion have been described in a position corresponding to the vector diagram in Fig. 4, that is, with the machine working as a generator, with a lagging current. This range of operation corresponds to the position of the current vector $A\,C$ in the upper left-hand quadrant comprised between the axes $X\,X$ and $Y\,Y$. When the vector $A\,C$ (Fig. 4) is directed along the $Y\,Y$ axis to the left, the generator load is non-inductive. When $A\,C$ is directed along the $X\,X$ axis upward, the current is

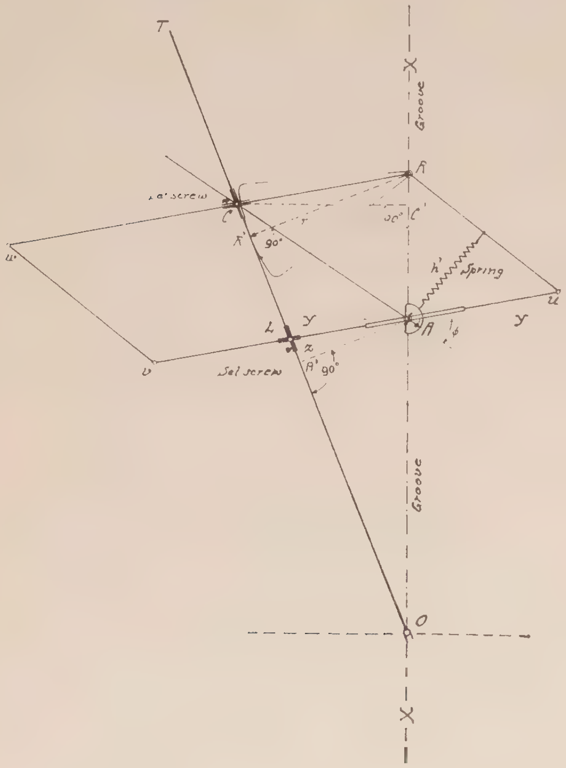

Fig. 9—The Load Device

lagging by 90 deg. behind the terminal voltage e. This is because the true position of the current vector i is that indicated in Fig. 3, lagging by 90 deg. with respect to $A\,C$.

When the vector $A\,C$ lies in the lower left-hand quadrant, it has an energy component to the left and a leading reactive component. Therefore this range corresponds to the operation as a generator with the current leading the terminal voltage. All the linkages of the Blondelion are so made as to enable a setting with either a lagging or a leading generator current.

In both right-hand quadrants the energy component of the current is reversed, so that when $A\,C$ lies to the right of $X\,X$, the machine is operating as a synchronous motor. When the reactive component of the vector $A\,C$ is directed upward, the machine furnishes a lagging current to the line, or as is more customary to express it, the motor takes a leading current from the line. It is known from the theory of the synchronous motor that for such an operating condition the machine must be overexcited. Conversely, the operation in the lower right-hand quadrant corresponds to a lagging component taken from the line, and to an underexcited motor.

It would be rather difficult so to design all the linkages of the Blondelion that they could be turned by 360 degrees about point A, without interfering with each other. Therefore, the device is assembled to cover the operation either mainly to the left or mainly to the right of the axis $X\,X$, according to whether the generator range or of the motor range is of most interest. In either case the transition from one range to the other can be readily observed.

A complete study of both the generator range and the motor range is also possible with one setting, by using the principle of images or reflection. Let the Blondelion be set for the generator range, and let it be desired to investigate the performance of the same machine as a motor. The true vector diagram then lies to the right of $X\,X$, but its image with respect to $X\,X$, considered as a plane mirror, lies in the generator range. Thus, the Blondelion can be set to the left of $X\,X$ and operated as an image of another, fictitious Blondelion, set to the right of $X\,X$.

When a watch is placed horizontally in front of a vertical mirror, its image seems to run counter-clockwise. Similarly, the image of a counter-clockwise vector diagram becomes a clockwise diagram. This fact must be kept in mind when operating the Blondelion as an image of a real diagram.

VIII. The Principal Dimensions of the Blondelion

Part (Fig. 2)	Length in Centimeters
$O\,T$	100
$A\,C$	70
$D\,D'$, $A\,N$, and $C\,N$	35
$p\,p'$	70
a	25
b	20
c	10
Radius of arc H-H	100
$w\,R$ and $v\,u$	85
$v\,w$ and $u\,R$	40
Radii of load sectors	19, 24, 29
Corresponding distances to the center line of $O\,T$	20, 25, 30

E. The Use of the Blondelion

The reader is now supposed to be familiar with the purpose and the construction of the separate parts shown assembled in Figs. 1 and 2. It remains to indicate how the device may be set for a given numerical problem. Let us assume the simplest case of an alternator for which the following data are either known from tests or have been estimated from the dimensions of the machine:

The no-load saturation curve;

The true armature reactance (*not* the synchronous reactance);

The direct armature reaction;

The transverse armature reaction.

Let it be required to set the Blondelion for this machine, for some given values of the terminal voltage e, armature current i, and phase angle ϕ.

First of all, suitable scales are selected for volts and for field amperes (or ampere-turns per pole). With these scales, the saturation device is set by trials to represent the given no-load e. m. f. curve as closely as possible. For details see the description of this device given above. Then the center A is fastened in the groove $X\,X$ at the desired point, to represent the terminal voltage e. The direction $A\,C$ is set with the protractor at A, to correspond to the desired value of the power factor or angle ϕ. The length $A\,D = i\,x$ is computed for the desired value of the armature current.

Next, the value of E_t' is computed according to eq. (**84**) on p. 156 of the "Magnetic Circuit." The value of the empirical coefficient (0.30) used there may have to be somewhat modified in accordance with the best data available for machines of the same type.[3] The proportional dividers $A\,N\,C$ are then opened so that $A\,C = E_t' + i\,x$, in accordance with the previously chosen voltage scale. The same opening $A\,C$ gives the desired armature current i, and therefore determines the scale of the armature current. By using an additional linkage ($C_2\,C_1\,N'$ in Fig. 6) the current scale can be made independent of the voltage scale. The length $A\,D$ can be now adjusted to equal the reactive drop $i\,x$ in the machine.

The figure $O\,A\,C$ thus having been set, the point G is automatically determined by the point D and by the direction $p\,p'$. The angle at D is therefore known, and the direct armature reaction, M_d, can be computed from formula (**79**) on p. 153 of the "Magnetic Circuit." The semi-empirical coefficient 0.75 in this formula may need some modification to suit the particular type of the machine investigated (see reference to Arnold above). The linkage $C\,K\,G$ is then set in such a way that $K\,G$ is equal to M_o to the same scale to which the field excitation is measured between G and Q.

The whole device is now set for that particular load, and after the desired readings have been taken, the parts can be shifted to any other desired performance point, and the new lengths and angles measured. In particular the following quantities may be kept *constant*:

(a) The field excitation, by placing a link of constant length between points S and K.

(b) The terminal voltage, by fastening the protractor A to one of the guides of the groove $X\,X$.

(c) The armature current, by fastening the bar $A\,C$ to its guide at C.

(d) The power factor, by fastening the bar $A\,C$ to the protractor at A.

(e) The power output, by fastening the guide at L (through which $u\,v$ passes) to the bar $O\,T$.

Even with one of these constraints, the device has more than one degree of freedom, so that it is possible to impose two constraints simultaneously. For example, both the field current and the load power-factor may be kept constant, and the relationship found between the armature current and the terminal voltage.

Sometimes the load characteristics of a machine are given, and from these it is required to estimate its armature reaction and reactance. The values of $A\,D$ and $K\,G$ are then adjusted by trials until the vector relationships obtained between the armature current, the terminal voltage, and the field excitation satisfy the available curves as well as possible (see the numerical example below). The final settings of $A\,D$, $A\,C$, and $G\,K$ permit to compute the armature reactance, and the two components of the armature reaction, and also to extend the available curves to other ranges of operation of the same machine.

Various problems in design and operation of synchronous machinery may be solved by means of the Blondelion, and wherever a direct setting is not possible, the linkages can be set by a few trials. With a mechanical device, such trials are quite simple, while they would be rather tedious or almost impossible with the usual analytical or graphical treatment.

With any setting of the Blondelion (Fig. 2), all or some of the following readings can be taken, depending on the purpose in view:

*Terminal voltage $O\,A$.

*Power factor, or the angle between the voltage e and the armature current i.

*Armature current $A\,C$.

*Field excitation, $S\,K$, in amps. or in ampere-turns.

Induced voltage $O\,G$, due to the main poles.

Induced voltage $G\,D$, due to the transverse armature reaction.

Total induced voltage $O\,D$, which is also a measure for the armature flux.

Reactance drop $A\,D$.

Direct armature reaction, $G\,K$, in field amps. or in ampere-turns.

Angle of deviation θ of the poles with reference to the terminal voltage.

Electrical input or output $O\,L$.

*Projection of i on the X and Y axes.

Any other angles between the vectors that may be of interest.

For obtaining the usual performance characteristic of the machine, only the quantities marked with an asterisk need be measured. From the quantities enumerated above the following results can be computed:

Voltage regulation curves.

Field excitation curves at a constant voltage.

Load saturation curves.

V-curves.

Input or output in kw.

Separate losses.

Efficiency.

Synchronizing force.

3. For values of this coefficient, k_q, and also of the coefficient of direct reaction, k_o, mentioned below, see E. Arnold, *Wechselstromtechnik*, Vol. IV, 1913, p. 34.

In an article on "Hunting and Parallel Operation of Synchronous Machines," *Sibley Journal of Engineering*, March 1920, the author has outlined a method of computation of the synchronizing force, taking into account the no-load saturation curve of the machine. The treatment is based on Blondel's theory of two armature reactions, and in the first approximation the no-load saturation curve is replaced by two straight lines at an angle. Even then the expression for the power transmitted electromagnetically between the field pole structure and the armature, as a function of the angle θ, is quite involved. The derivative of this power with respect to θ by definition is the synchronizing power, and its expression is also rather complicated. In the Blondelion the increase in the power $O\,L$, for a certain small variation of the angle θ, can be read directly, and the synchronizing force, $\Delta\, O\,L/\Delta\,\theta$, easily computed. Thus, the device should prove useful in flywheel computations and in problems on hunting of synchronous machinery.

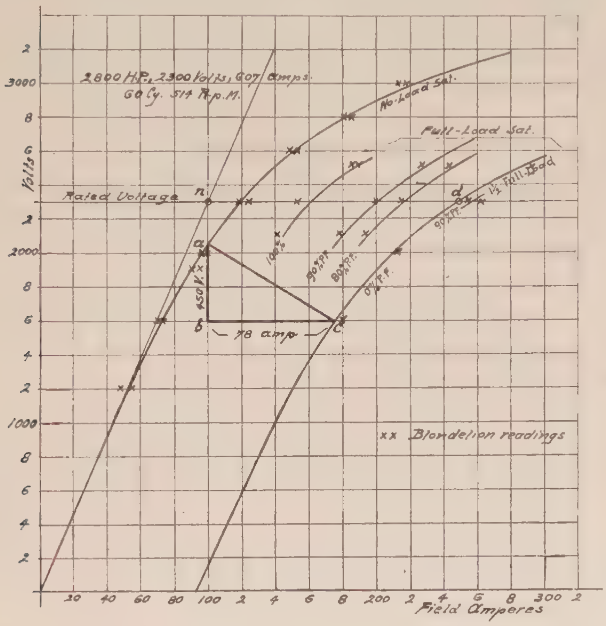

Fig. 10—No-Load and Load Saturation Curves of a Westinghouse Synchronous Machine Operating as a Generator

F. Numerical Examples and Comparison with Experimental Data

Complete performance characteristics of two actual machines have been obtained by means of the Blondelion and the results compared with the available experimental data on the same machines. In Figs. 10 to 13, the curves represent the actual test results, while the crosses are the readings taken on the Blondelion. The no-load saturation curves (Figs. 10 and 12) were read on the Blondelion with both an increasing and a decreasing voltage, and a slight discrepancy between the two is due to some lost motion in the device. Load curves were checked for each machine working both as a generator and as a motor, and the agreement in all cases has been found satisfactory.

The test curves on the two machines and the other data quoted below were kindly furnished to the author by the engineers of the Westinghouse Electric and Manufacturing Co., and of the Allis-Chalmers Co., to whom he wishes to express his sincere gratitude. The principal data are as follows:

Make	Westinghouse	Allis-Chalmers
Rating as synchronous motor, H. P.	2800	500
No. of phases	3	3
Frequency in cycles	60	60
Rated voltage	2300	2200
Amperes per phase	607	105
Rated at a power factor of	0.90	1.00
Speed, rev. per min.	514	450
No. of poles	14	16
Stator connection	Y Y	Y
Slots per pole per phase	3	3
Coil lies in slots	1 and 8	1 and 8
Conductors per slot	6	6
Armature I^2R in kw.	9.9 (at 75 ° C)	4.1
Field turns per pole	68.5	83.5

First of all, the saturation device was set to represent the no-load saturation curve of the Westinghouse machine shown in Fig. 10. The point n, defined in Fig. 5, corresponds in this case to a field current of 100 amperes and to a terminal voltage of 2300. The saturation device was set accordingly for the lengths

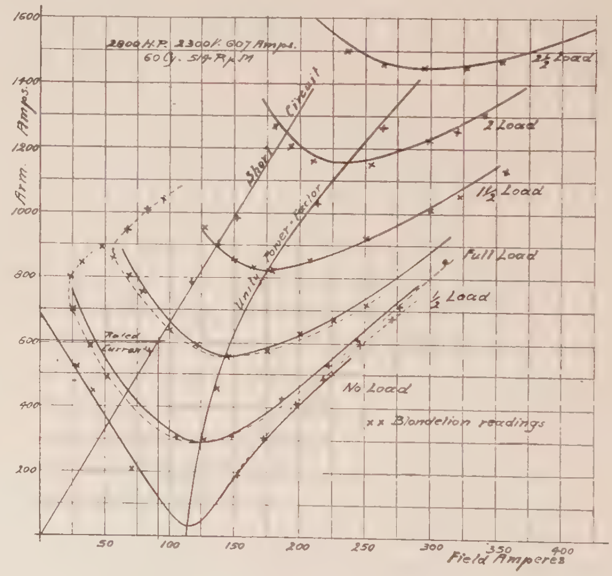

Fig. 11—The Short-Circuit Curve and the V-Curves of a Westinghouse Synchronous Motor

100 amperes = 18 cm. and 2300 volts = 45 cm., on the straight part of the saturation curve. The curved plates were then adjusted to give the upper part of the no-load characteristics. It will be noted that the "delta" or terminal voltage was used, and not the Y-voltage; all other voltage vectors in the Blondelion were set in terms of this voltage.

The next step was to estimate the direct armature

reaction and the reactive drop, from the load saturation curve at zero power factor. The no-load saturation curve of the machine was traced on a piece of thin paper and shifted by trials diagonally, parallel to itself, until it fitted as well as possible the upper part of the load saturation curve at zero power factor. The line $a\,c$ (Fig. 10) gives the distance and the direction of the shift. The horizontal distance, $b\,c$ = 78 field amperes, represents the direct armature reaction; the vertical distance, $a\,b$ = 450 volts, gives the reactive drop.[4]

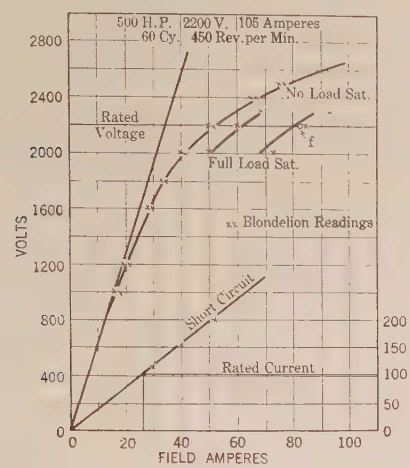

FIG. 12—PERFORMANCE CHARACTERISTICS OF A ALLIS-CHALMERS SYNCHRONOUS MACHINE OPERATING AS A GENERATOR

These values hold well within the operating range of the machine, but are a little large for the short-circuit point, on account of the well-known increase in the reactance and leakage with the saturation.

The above obtained value of the direct reaction can be checked by means of eq. (**79**) on p. 153 of the "Magnetic Circuit." Namely, when ϕ = 90 deg., the angle ψ is so nearly equal to 90 deg. that sin ψ is almost equal to unity. We therefore have,

$$M_d = 0.75 \times 0.96 \times 0.94 \times 3 \times 9 \times 0.5 \times 607$$
$$= 5550 \text{ ampere turns.}$$

In this expression 0.5 is introduced, because the two halves of the armature winding are connected in parallel. In terms of the field winding this m. m. f. corresponds to

$$5550/68.5 = 81 \text{ amperes}$$

which checks well with the value 78 amperes derived above from the experimental curves. The value of the reactive drop, 450 volts, was also checked theoretically from the dimensions of the machine, and a satisfactory agreement found between the two.

The scale for the field current being 100 amperes = 18 cm., the distance $G\,K$ at the rated armature current must be equal to 18 × (78/100) = 14 cm.

The next step was to estimate the transverse armature reaction. Using expression (**84**) on p. 156 of the "Magnetic Circuit," with a different numerical coefficient, we get

$$E_t' = 0.43 \times 0.96 \times 0.94 \times 3 \times 9 \times 0.5 \times 607$$
$$\times\ 2300/(100 \times 68.5) = 1070 \text{ volts.}$$

In this expression the coefficient 0.43 was used in place of 0.30, in accordance with the later data than those upon which the values given in the "Magnetic Circuit" were based.[5]

Thus, at the rated current, the proportional dividers must have an opening

$$A\,C = (1070 + 450) \times 45/2300 = 30 \text{ cm.}$$

The current scale is 607/30 = 20.2 ampere per cm.

The point D was determined so as to give the ratio

$$D\,C : A\,D = 1070 : 450$$

and the setting was done for the nearest ratio possible with a limited number of holes.

After this, the device was set with $O\,A$ = 2300 volts = 45 cm., the power factor Cos ϕ = O, $A\,C$ = 30 cm., and $G\,K$ = 14 cm. This gave the point d (Fig. 10). Then, keeping the power factor constant, the point A (Fig. 2) was shifted up and down along $X\,X$ and the remaining points on the curve checked.

In a similar manner the points on the other load curves were determined, at the corresponding values of power factor. Finally the center A was shifted as near as possible to O, and a few points checked on the short-circuit curve (Fig. 11). In this case the length $A\,C$ was varied, to get different values of the armature current.

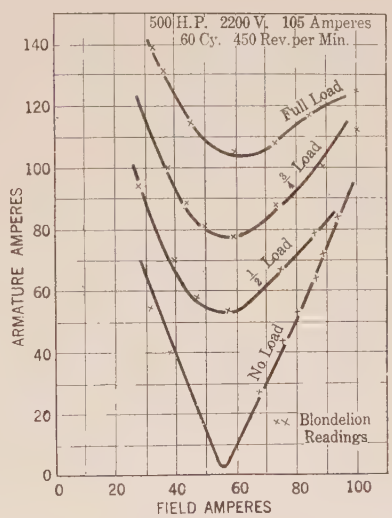

FIG. 13—V-CURVES OF AN ALLIS-CHALMERS SYNCHRONOUS MOTOR

The V-curves, shown in Fig. 11, were checked as follows: The machine being rated as a motor at 607 amperes and 90 per cent power factor, the bar $A\,C$ was set at 0.9 × 607 = 546.3 amperes at right angles to the groove $X\,X$. By means of the set screw j' (Fig. 8) the point A was fastened to keep the terminal voltage con-

4. See the author's "Experimental Electrical Engineering," Third Edition, 1923, Vol. I, pp. 564 to 566.

5. E. Arnold, *loc. cit.* For the ratio of the pole arc to pole pitch of 0.70 he gives k_q = 0.446.

stant and equal to 2300 volts. The saturation device and the load device then automatically assumed their proper positions. The set-screw z at L (Figs. 2 and 9) was then tightened to keep the power input into the machine constant. The field current was read.

After this, the bar $A\ C$ was turned stepwise, by a few degrees at a time, and the new field and armature currents were read at each step. This was done for a lagging and a leading current and the points so obtained were marked by crosses on the full-load V-curve shown in Fig. 11. The length $O\ L$ was then reduced to one half, and similar points were obtained, shown on the half-load V-curve. Subsequently the V-curves at 1½, 2 and 2½ times full load were checked, by setting $O\ L$ equal to that many times its length at the rated load. The no-load V-curve was checked by making $O\ L = O$. The curve which connects the lowest points of the V-curves, that is, the unity power factor curve, was checked by setting the screw j' so as to keep the power factor at 100 per cent, and varying the field current and the armature current. The load device was not used in this last test.

The curves of the Allis-Chalmers machine, shown in Figs. 12 and 13, were checked in a similar manner, and it would be a needless repetition to quote here the numerical data. It must be stated, however, that no actual load tests were made on this machine running as a generator. The maker of the machine stated to the author that the curves in Fig. 12 at 90 and at 100 per cent power factor were computed by the A. I. E. E. method and that the point f was estimated from tests on similar machines.

The writer's assistant, Mr. O. K. Marti, actually built the device and performed all the measurements described above. To him credit is also due for several mechanical details and for the drawings used in this paper. The author wishes to express to him his sincere appreciation of the valuable assistance rendered.

CARRIER CURRENT TELEPHONE BETWEEN HOLTWOOD, PA. AND BALTIMORE, MD.

The Pennsylvania Water & Power Company recently completed an installation of carrier current telephony between its generating station at Holtwood, Pa., and its Highlandtown substation at Baltimore, Md., 40 miles away, whereby the four 70,000-volt transmission lines are used to conduct the high-frequency alternating current employed as a carrier for telephony and signals. This system was installed to supplement a private telephone service over two physical circuits of No. 9 B. & S. copper paralleling the tower lines on a private right-of-way. These physical circuits are giving excellent service except for those rare occasions when lightning or grounds on the high tension lines may render communication difficult.

The simplex system has been adopted for both talking and calling. Two frequencies are employed, one for talking and the other for calling signals. Coupling wires are placed over both tower lines for a distance of 1265 feet at Holtwood and 780 feet at Highlandtown so that all four circuits provide a path for the carrier current. Existing ⅜-in. galvanized steel ground cables were used as coupling antennae by inserting insulation between cable and tower.

The transmitter consists of two 50-watt U. V. 203 vacuum tubes, one of which is used for the oscillator and the other for the modulator. The oscillating circuit consists of the coupling wire, oscillation transformer and series condenser. For the receiver a standard two-circuit vacuum tube hook-up is used for the talk and call signals and a special relay is employed in the plate circuit of one tube to ring a call bell. Relays are provided in both the transmitter and receiving circuits to select the proper taps corresponding to the call and talk frequencies. Power is supplied from the 220-volt direct-current control battery to run a motor-generator set which supplies 1000 volts for the plates of the transmitting tubes and also alternating current for heating the filaments. A 6-volt storage battery is used for heating the receiving tube filaments and to operate the relays and control circuits.

A number of tests were made on the carrier equipment to compare its operation with that of the physical lines under the condition of ground current flowing between Holtwood and Baltimore. These tests showed that conversation could still be carried on in both directions when the physical lines were completely out of commission due to blown fuses and failure of the vacuum lightning arresters.

Another series of tests was made in which certain circuits were taken out of service and grounded at Holtwood and Baltimore. It was found that with the coupling wires used on all four circuits as high as two circuits could be grounded at both ends with practically no effect on the talking and calling. Certain other tests were also made which indicated that if only one conductor were ungrounded all the way through it would still be possible to talk and call in both directions.

The entire equipment was furnished by the General Electric Company in Schenectady, which is also working on other similar lines. The power company is contemplating a similar carrier current installation for the two 70,000-volt circuits between the Holtwood power house and the substation at Lancaster, Pa.

N. E. L. A. Bulletin.

Life tests of the pure platinum and platinum-rhodium wire prepared at the Bureau of Standards for thermocouples have been carried out by the Bureau. Results thus far obtained indicate that couples of material purified, melted, and drawn to wire at the Bureau are superior to the best commercial couples previously tested.

A New Method for the Routine Testing of Alternating-Current High-Voltage Paper-Insulated Cable

By HOWARD S. PHELPS and E. DEAN TANZER

Associate, A. I. E. E. Associate A. I. E. E.

Both of the Philadelphia Electric Company

Review of the Subject.—*The usual methods of testing alternating-current high-voltage paper-insulated cables are based upon the ability of the insulating material to withstand excessive potentials in order to determine its condition. Accordingly, these methods are not suitable for routine tests imposed for the purpose of determining the degree of deterioration existing in any particular cable.*

In an effort to develop a routine test, which will serve to detect an impending fault, use has been made of the kenotron as the source of high-potential direct-current. By means of it a large volume of data has been secured concerning the input-current, for a cable, as a function of time after complete electrification at a constant high potential. These data when plotted, as curves, show by their shape the condition of the cable insulation.

Curves showing a sharp decrease in the magnitude of input-current during the first minute and a gradual but persistent rate of decay for the succeeding six or seven minutes indicate that the insulation is in an acceptable condition from the operating point of view.

Curves showing little, if any, decrease or a persistent tendency to increase during the time interval of the test indicate that the insulation has deteriorated to such a point that the cable may be expected to fail at an early date if retained in service. The degree of deterioration is indicated first: by the time which has elapsed since complete electrification before the increase occurrs, and second: by the sharpness of the upward trend of the curve in any instance.

The value of this method of testing has been demonstrated by its actually having detected a considerable number of impending cable faults before they became a menace in operation.

Additional refinements in the methods of measuring the input-current for different classes of cables may be desirable. Further investigations are being carried on to determine this necessity. Investigations of certain theoretical features are also being carried on. These include, among other things, oscillographic studies of the input-current and voltage under test conditions.

CONTENTS

Introductory—The Problem

With the expansion of underground transmission alternating-current networks, as regards both extent and operating voltages, the problem of determining the condition of the feeders has become more and more complex. The size and cost of alternating-current equipment for testing cables in modern underground systems is a matter of no small importance. With the high-transmission voltages and increased feeder lengths, these two factors approach limits which are almost prohibitive.

Also, the usual alternating-current test schemes have only determined the ability of a specific cable to withstand a particular test voltage; usually much in excess of that in normal operation. In our opinion a more desirable test method must include not less than the following features:

1. Should, if possible, be capable of detecting abnormal conditions in a cable at a sufficiently early date to permit of their location and elimination prior to the time at which they would constitute a menace to the system.
2. It should be effective at an impressed potential sufficiently low to insure that the insulating material will not be over-stressed.
3. Simplicity.

Due to the desire to develop a test, independent of the actual destruction of the material, to determine its acceptability, no consideration has been given the question of relative effects of test voltages impressed on cables by the kenotron or by the usual alternating-current tests; *i. e.* the ratio of kenotron to alternating-current potential for equal electrical stresses on the cable has not been considered in this investigation. Also, no attention has been given the problem of determining the geographical location of any particular fault.

Accordingly we have, for over four years, been investigating the possibility of developing such a test method. Because of certain rather outstanding conditions existing in the alternating-current feeders for the Edison system, and the necessity of safeguarding against interruptions due to cable failures, that portion of the transmission network was utilized in the study.

At the time this study was inaugurated The Edison District of The Philadelphia Electric Company was supplied with energy principally by means of 6,000-volt, a-c., 60-cycle, two-phase, three-conductor underground transmission feeders. These feeders constituted direct ties between the generating and substations. They had been installed for a number of years and were manufactured prior to the production of low dielectric loss cables. The cables referred to are practically all 250,000 cir. mil cross-section, insulated with 5/32-in. by 5/32-in. paper impregnated with rosin oil compound. Their lengths vary between 12,000 and 18,000 feet.

The alternating-current supply system for the Edison District has been considerably augmented, beginning the latter part of 1920, by the addition of high-efficiency 13,200-volt, three-phase paper-insulated lead-covered transmission cables.

Presented at the Midwinter Convention of the A. I. E. E., New York, N. Y., February 14-17, 1923.

During the season of 1920 there were a number of unfortunate experiences with the operation of this portion of the transmission systems. This condition was brought about by several circumstances, among which the following may be noted:

1. The Edison load at that time was closely approaching the rated capacity of the substations and on that account if trouble developed, at any point, it was almost certain to cause a rather general interruption in the Edison District by tripping out other substations. This condition was especially true if a transmission feeder failed in service, since it probably would cause other feeders, working in parallel with it, to trip out.

2. The heavy loading of the alternating-current feeders, supplying the Edison system, tended to develop, through heating, inherent weaknesses in their insulation. Consequently, it became imperative that the utmost care be used in operating this portion of the underground system.

Several years ago The Philadelphia Electric Company secured a 60-kv., 0.1-ampere single-tube kenotron set in order to determine what, if any, possibility there was of applying a high-voltage direct-current test to underground transmission feeders to ascertain the general operating condition of such cables. The first thought was to consider the kenotron as a high-voltage megger, and from the observed values of current and impressed voltage to calculate the insulation resistance. It was immediately found that the current varied over an extremely wide range, from a large magnitude, at the instant of electrifying the cable, down to a value of 1/3 to 1/4 as great after several minutes of electrification. From this it was seen that a wide range of calculated insulation resistance values could be readily obtained and no decision could be made as to which of these, with respect to elapsed time, should be considered as representing the condition of the cable.

In addition to the apparent wide deviation in insulation resistance just noted it was observed that the current for a given cable when electrified to the same potential, but on different days, might vary over an extremely wide range; possibly of the order of 200 to 300 per cent variation. This latter situation is, undoubtedly, associated with the temperature of the insulating material at the time of test. However, as no feasible method was available for determining the temperature of a cable throughout its length, the combination of circumstances giving rise to wide variations of current seemed to preclude the use of the kenotron.

In view of the operating difficulties experienced in 1920, added consideration was given to the possible application of the kenotron for the purpose originally in mind; *i. e.* determination of the condition of cable insulating material. From what had been done earlier it was apparent that another method of analysis must be developed. Accordingly, consideration was given to plotting the tabular data on rectangular coordinate cross-section paper. It was hoped that the resulting curves might indicate the general character of the cable insulation. Here again, however, the wide variation between tests on successive days seemed to complicate the problem.

The next step was to analyze some of the tabular data[1] with the hopes that the equation expressing the relation of the constants in the curve might be determined. It was very soon found that these constants apparently obeyed no definite law.

Another method of analysis employed was to plot the data on semi-logarithmic paper. The results confirmed the earlier deductions that the current-time curves were not represented by a simple mathematical function.

The very high initial value of current, together with its more or less uniform rate of decay, apparently indicated characteristics similar to those of an electrical condenser. Since it required a long period of time—of the order of many minutes—before the current reached a value which was reasonably constant it was also evident that the condenser characteristics exhibited were not those usually considered, but must represent a charge absorbed within the dielectric. Finally, the approximately constant value of current observed after an extended period probably represents the true leakage current through the insulation.

From the foregoing it was concluded that the shape, rather than the magnitude, of the current-time curves for any particular cable might be indicative of the condition of its insulation.

It was then determined that a large volume of data should be obtained with the hope that, possibly, its analysis might produce something more indicative than had been found in the limited material previously available. During the accumulation of this added information some rather interesting developments were noted in the results of the tests and it was deemed advisable to follow them further.

Methods of Testing

Due to the many variables complicating this problem, an early effort was made to minimize their influences by conducting the kenotron tests in as nearly a uniform manner as possible.

In order that the data for different tests might be comparable, it was deemed advisable to energize the cables to the same potential in each case. Because of the age of the feeders in the 6000-volt system, an aversion to subjecting them to abnormal potential stresses, together with lack of knowledge as to what effect the kenotron tests might have upon cable insulation, it was decided to use 9000-volts, which approximates the peak value of the wave for these two-phase circuits, on 6000-volt feeders when testing them by kenotron.

As it had been decided that a study should be made to determine what, if anything, could be learned from the shape of the current-time curves, it was felt advisable to electrify the cables under test at a standard

1. Steinmetz, Engineering Mathematics.

uniform rate. It was found that the kenotron voltage could be raised very readily at a rate of 1500-volts per second, that is, a time interval of six seconds would be required in which to bring it up to test value. Therefore, this rate of electrification was adopted as standard. Operators making tests were accordingly instructed to close the high-voltage test switch at 54 seconds and to raise the voltage, as uniformly as possible, at a rate such that the test voltage, 9000 volts, would be reached at 60 seconds exactly. See Fig. 1.

In order to eliminate, as far as practicable, any unexpected effects due to adjustment of the kenotron voltage the attention of the operator was called to the necessity for care in approaching the final test value. This was done to minimize the possibility of imposing upon the cable a final voltage exceeding that desired; thereby necessitating reduction.

Having fixed the rate at which electrification should be applied, the time intervals at which readings were to be taken were arbitrarily set as follows:

Initial reading upon completion of electrification and subsequent readings at 15, 30 and 45 seconds and at 1, 2, 3, 4, 5, 6, 7 and 8 minutes after completion of electrification; a complete time interval of 480 seconds after full test voltage had been reached.

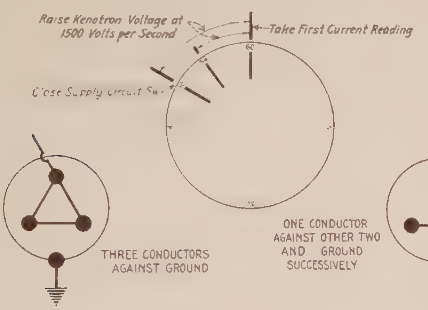

FIG. 1 —METHOD OF TIMING AND CONNECTIONS USED IN DETERMINATION OF CABLE CURRENT TIME CURVES

The sequence of tests selected, see Fig. 1, was as follows:

1. Three conductors together against sheath and ground.
2. Phase *A* against *B-C* and sheath to ground.
3. Phase *B* against *A-C* and sheath to ground.
4. Phase *C* against *A-B* and sheath to ground.

Therefore, omitting the time required in changing connections and other unavoidable delays, not less than 32 minutes has been required to test a single feeder.

The foregoing instructions were prepared in concise form for the guidance of those in the Station Operating Department who were responsible for routine electrical testing, and mimeographed forms for tabulating the data were furnished. See Fig. 2. This placed the operation as nearly as possible on a routine basis, which was desirable for the purpose of learning how practical this scheme of testing would prove.

Upon receipt of the tabular material, for the several tests, from the Station Operating Department, the

THE PHILADELPHIA ELECTRIC CO.

Date..................

Test by..................

Kenotron Test on Cable # ....

Between Schuylkill Station and ....

Leakage Current in Milliamperes at 9000-V. D.C.

Feeder off Line ....M.

Av. amperes Load: A ϕ =

Past 5 hours : C ϕ =

	Time	Time	Time	Time
Schedule of Readings	*A-B-C* to *GRD*	*A* to *B-C* & *GRD*	*B* to *A-C* & *GRD*	*C* to *A-B* & *GRD*
Start				
15 seconds......				
30 "				
45 "				
1 minute				
2 minutes......				
3 "				
4 "				
5 "				
6 "				
7 "				
8 "				

NOTE: The cable is to be electrified at the rate of 1500 volts per second. To do that have Kenotron bulb working and then close high voltage d-c. switch 6 seconds before minute and raise voltage at uniform rate to test value of 9000 volts in period of time noted. When the required test voltage is reached on the minute make first reading and enter opposite "start". Make other readings 15-30 and 45 seconds and 1-2-3-4-5-6-7-8 minutes after voltage reached the test value.

Check zero reading of voltmeter and ammeter and if necessary adjust by means of small flat head screw in lower flange of instrument cases before making test.

Make note of abnormal conditions such as breakdown of spere gap.

FIG. 2

observed values of current were reduced to units of current per mile in order to facilitate direct comparison of results observed on different feeders. Much of the material has been plotted in curves similar to those which appear here.

DATA AND OBSERVATIONS

Referring to Figs. 3 and 4 which show a group of current-time curves from successive tests on feeder 112 for a period of several weeks, some interesting things may be observed.

These data are plotted to semi-logarithmic coordinates with the logarithm of the current, in milliamperes per mile at 9000 volts, as the ordinate and the time, in seconds, plotted uniformly as the abscissa. It is observed that for the tests of February 25, 1921, (Fig. 3), there is a very sharp decrease in current, from its

initial value, during the first 30 seconds. For the remainder of the eight minutes, the current decreased rather slowly and at a fairly uniform rate. It is also interesting to note the variation in the characteristics of the insulation for each of the three conductors of the cable, as brought out by the curves representing tests

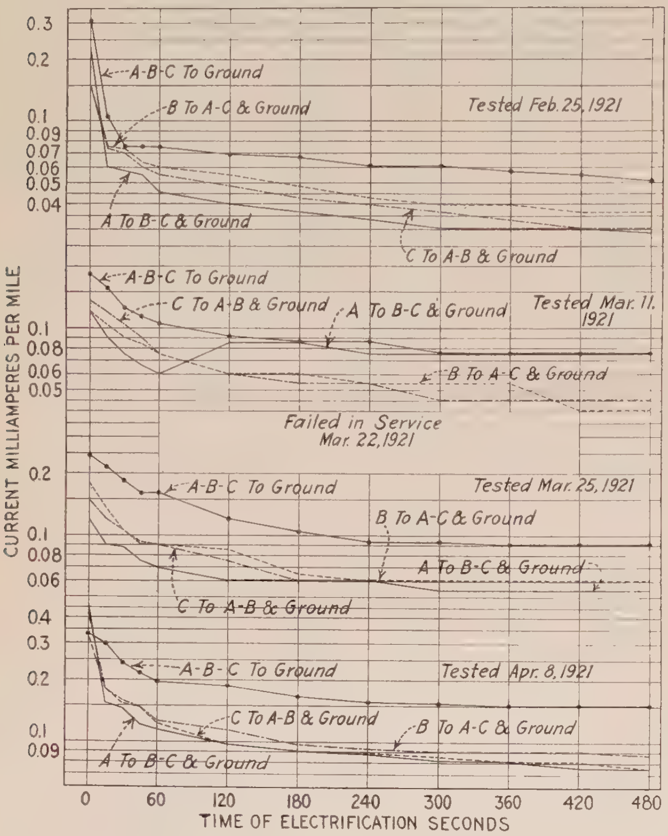

Fig. 3—Current-Time Curves

At 9000-volts electrification by kenotron feeder 112; operating voltage . kv.; $\frac{5 \times 5 \text{ in.}}{32}$ impregnated insulation, 3 × 250,000 = cir. mil. conductors; feeder length 17,487 ft.

on each of the several conductors when measured against the other two connected to the sheath and to ground.

The tests of March 11th (Fig. 3) show an entirely different situation both as to absolute value of the initial current and outline of the curves. Here again, special attention should be paid to the curves for each of the several conductors. It is noticed that the plotted data for phase *B*, when tested against the other two conductors and the sheath to ground, and phase *C*, tested in a similar fashion, have a rather uniform downward slope. On the other hand, the curve representing phase *A* when tested against *B-C* and ground, shows a decreasing characteristic during the first 60 seconds after which time the current abruptly increased. At the end of two minutes, after electrification of the cable, the value of current on phase *A* is only about 25 per cent less than its initial value and it continues for the balance of the eight-minute period at a magnitude not differing materially from this. Sufficient data had not been obtained, up to the time this material was plotted, to give a clue as to what this sharp upward trend, or inversion, of the curve indicated. Subsequent events seemed to bring out this matter very clearly, for on March 22nd, or eleven days after the test under discussion, the cable failed in service.

Tests made March 25th and April 8th, (Fig. 3), after the cable had been repaired and restored to service, showed characteristics similar to those on February 25th; *i. e.* a gradual decay of the current from the instant of electrification.

The plotted data for tests of April 22nd, (Fig. 4), again showed that an abnormal condition existed. During the first 60 seconds the current for all three phases, tied together and tested against the sheath and ground, decreased quite sharply, but after that time the current arose very abruptly and at the end of 8 minutes was approximately 30 times its initial value. With this indication the kenotron test was discontinued and the cable was connected to the regular high-voltage a-c.

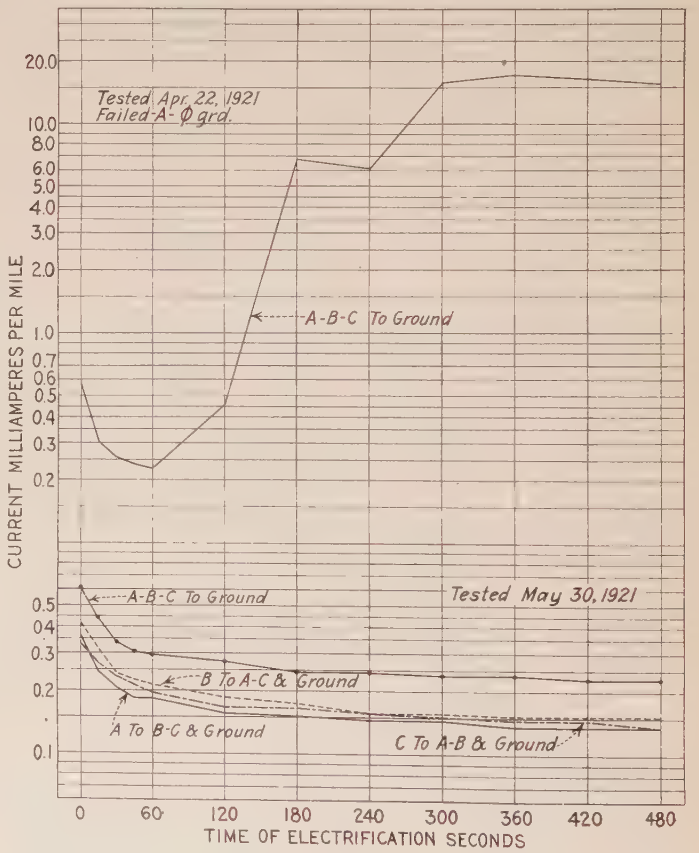

Fig. 4—Current-Time Curves

At 9000-volts electrification by kenotron feeder 112; operating voltage 6.0 kv.; $\frac{5 \times 5 \text{ in.}}{32}$ impregnatedins ulation; 3 × 250,000 = cir. mil. conductors; feeder length 17,487 ft.

test set and it was found that the insulation on phase *A* broke down at a low impressed a-c. potential.

Tests made again on May 30th, (Fig. 4), produced a series of curves apparently free from abnormal characteristics.

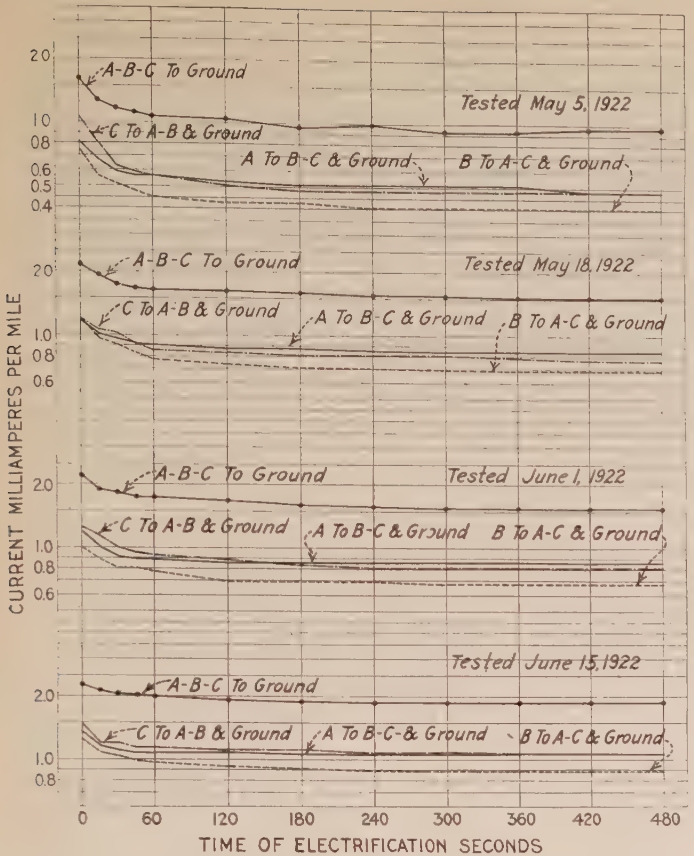

Fig. 5—Current-Time Curves

At 9000 volts electrification by kenotron feeder 109; operating voltage 6.0 kv.; $\frac{5 \times 5 \text{ in.}}{32}$ impregnated paper insulation; 3 × 250,000 = cir. mil. conductors; feeder length 19,725 ft.

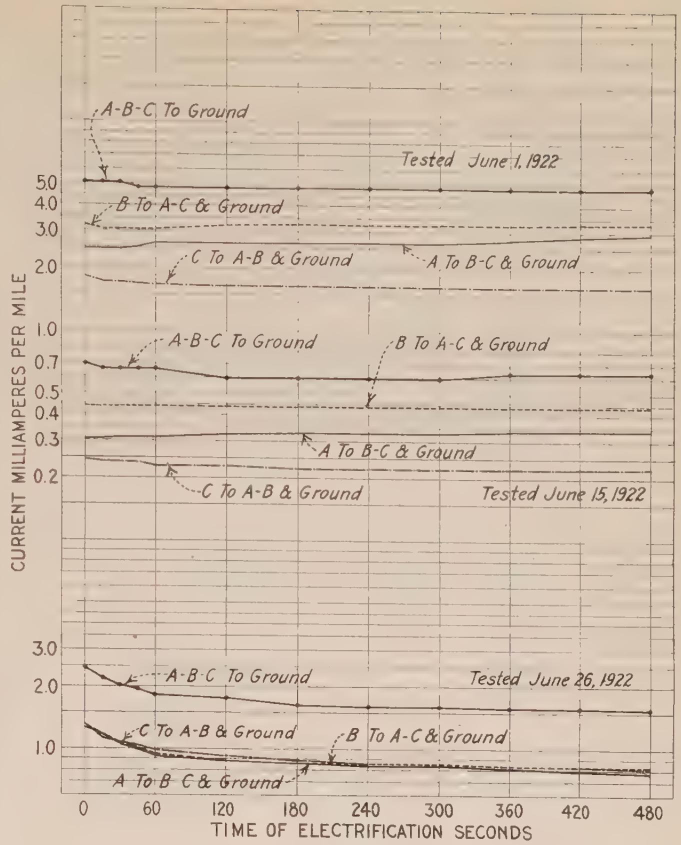

Fig. 7—Current-Time Curves

At 9000-volts electrification by kenotron feeder 116; operating voltage 6.0 kv.; $\frac{5 \times 5 \text{ in.}}{32}$ impregnated paper insulation; 3 × 250,000 = cir. mil. conductors; feeder length 12,075 ft.

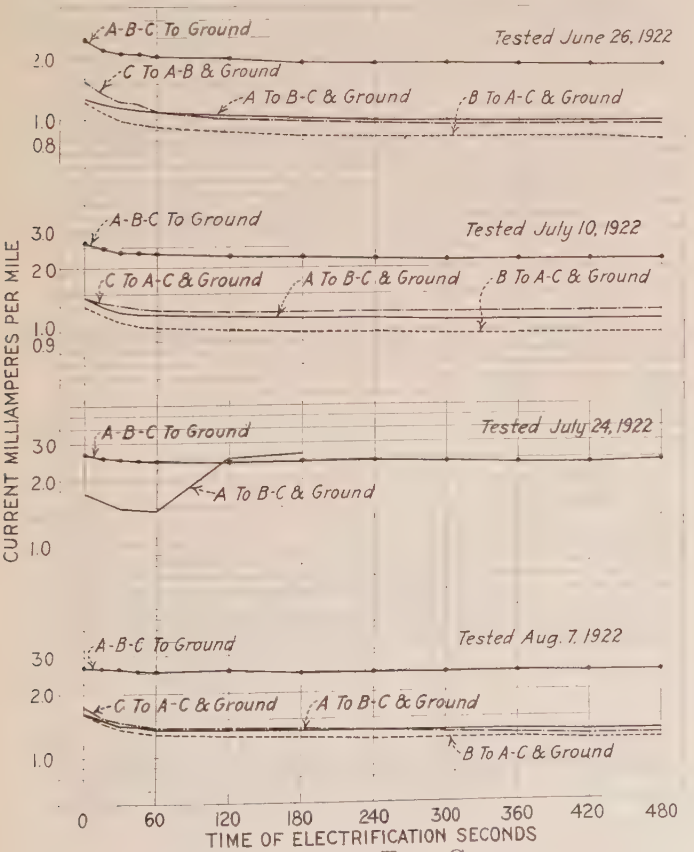

Fig. 6—Current-Time Curves

At 9000-volts electrification by kenotron feeder 109; operating voltage 6.0 kv.; $\frac{5 \times 5 \text{ in.}}{32}$ impregnated paper insulation; 3 × 250,000 = cir. mil. conductors; feeder length 19,725 ft.

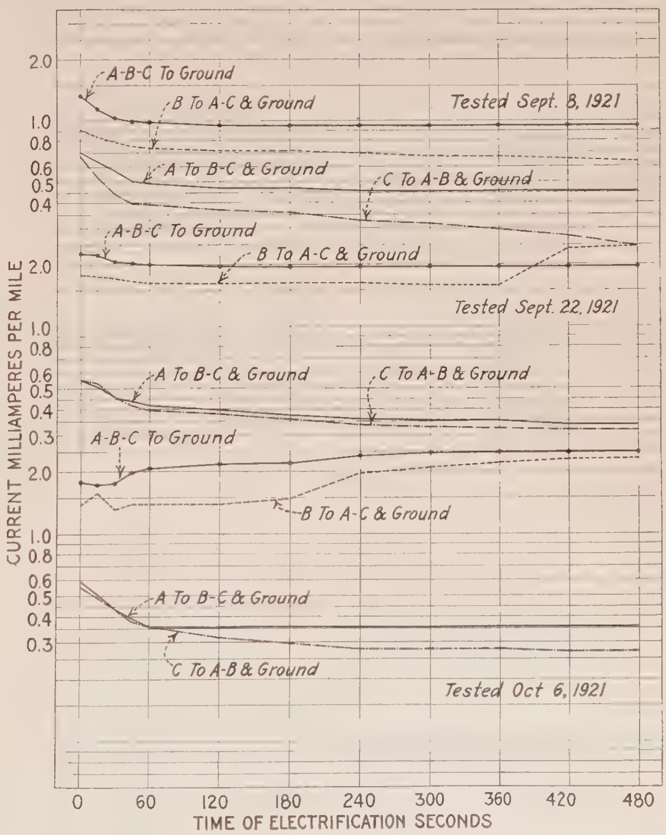

Fig. 8—Current-Time Curves

At 9000-volts electrification by kenotron feeder 122; operating voltage 6.0 kv.; $\frac{5 \times 5 \text{ in.}}{32}$ impregnated paper insulation; 3 × 250,000 = cir. mil. conductors; feeder length 13,234 ft.

Recognition of Apparent Solution

Referring again particularly to the tests of March 11th, (Fig. 3), and April 22nd, (Fig. 4), it was felt that the sharp inversion of the curves must be indicative of an unsatisfactory condition of the insulation, since the inversion was followed by an actual breakdown of the particular cable a few days later in the one case, and in the other it was found that the insulation had little, if any, dielectric strength.

Here, then, was a means by which it seemed that it might be possible to determine, through routine tests, the development of faults in cable insulation and to learn of their presence sufficiently early to permit locating them prior to their causing a failure of the cable while in service. The operating results which have been obtained through this method of testing have been most interesting as may be seen from the following test data for other feeders of the 6000-volt system as shown in Figs. 5, 6, 7, 8 and 9.

Additional Data and Observations

The curves of Figs. 5 and 6 for feeder 109 show quite clearly the progressive nature of the development of a fault, even though the cable was retained in active service and there were no indications, in its operation, of the situation which was impending.

Beginning with the tests for May 5th, 1922, (Fig. 5), the curves for the successive tests indicate more and more the predominance of the leakage current through the insulation, as disclosed by the absence of any marked decrease in the magnitude of the current. This represents the condition where the leakage current of the condenser becomes larger and larger in comparison with the charging currents. Finally, with the test of July 24th, (Fig. 6), the cable was found to be defective. The flatness of the curves, from the test following repairs to the cable, appeared to indicate that the feeder was not yet in really good condition.

The curves of Fig. 7 for feeder 116 show that two impending failures were detected before their occurrences in service. The tests of June 1st and 15th, (Fig. 7), brought to light conditions in the paper insulation such that complete breakdown occurred at 7500-volts on the a-c. test set. The tests of June 26th showed the cable to be in much better condition, following the elimination of the faults located earlier, as indicated by the decrease of current with elapsed time when compared with the slight decrease, or even marked rise, detected in the tests of June 1st and 15th.

The curves of Figs. 8 and 9 for feeder 122 show quite clearly the progressive deterioration of cable insulating materials, as well as the wide differences that may develop in the characteristics of the insulation of the different conductors in a cable. Curve B in the tests of September 22nd and October 6th, (Fig. 8), shows quite clearly, both by the magnitude and form, that the condition of the insulation of that conductor is radically different from that of the other two.

During the year 1922 twelve 6000-volt feeders have been subjected to a routine test by the kenotron at regular intervals of about two weeks. Whenever the test data indicated that the current had a persistent tendency to increase, the cable has been subjected to a high-voltage a-c. test after the completion of the kenotron test. In some twenty instances it has been found that the insulation failed at from 2000 to 7500 volts under a-c. potential. In a few instances the tabular data have indicated a rise in the current value but the

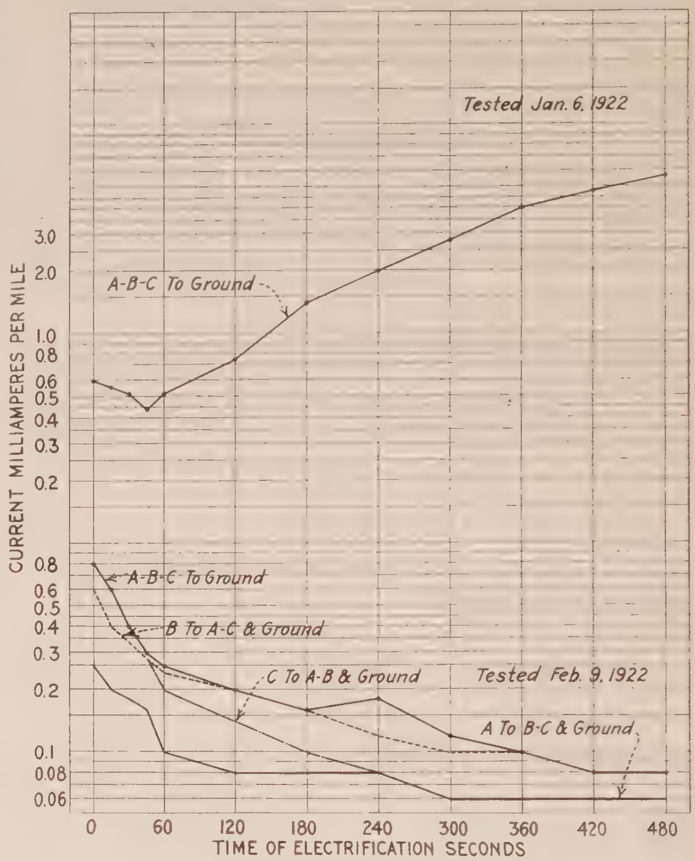

Fig. 9—Current-Time Curves

At 9000-volts electrification by kenotron feeder 122; operating voltage 6.0 kv.; $\frac{5 \times 5 \text{ in.}}{32}$ impregnated paper insulation; 3 × 250,000 = cir. mil. conductors; feeder length 13,234 ft.

incipient fault had not developed sufficiently to cause the cable to fail when placed under a-c. test.

During 1922, by using this method of test, some twenty impending failures have been detected before their actual occurrence, with the net operating result that in only one case has a feeder actually failed while in service. This one instance was undoubtedly due to the fact that it was necessary to discontinue the routine kenotron tests temporarily. The failure occurred during the time the tests were not being made.

Examination of a considerable number of faults which have been predetermined by the kenotron has not disclosed any evidence of over-stressing of the insulating material. The several faults which have been detected to date have had legitimate mechanical explanations, as for example, cracked lead, lead worn through where

the cable has come in contact with the edge of the duct, wrinkled insulating paper or non-uniformity in the construction of splices.

In addition to the investigation which has been carried out on the 6000-volt feeder system some work has also been done in the application of this proposed test method to 13,200-volt, three-phase cables. While the volume of data, which has been obtained to date from these latter tests, is not as extensive as for the tests on the 6000-volt feeders, the resulting current-time curves, (Fig. 10), have not differed materially in shape from those under discussion. Indications are, therefore, that this method of test is directly applicable

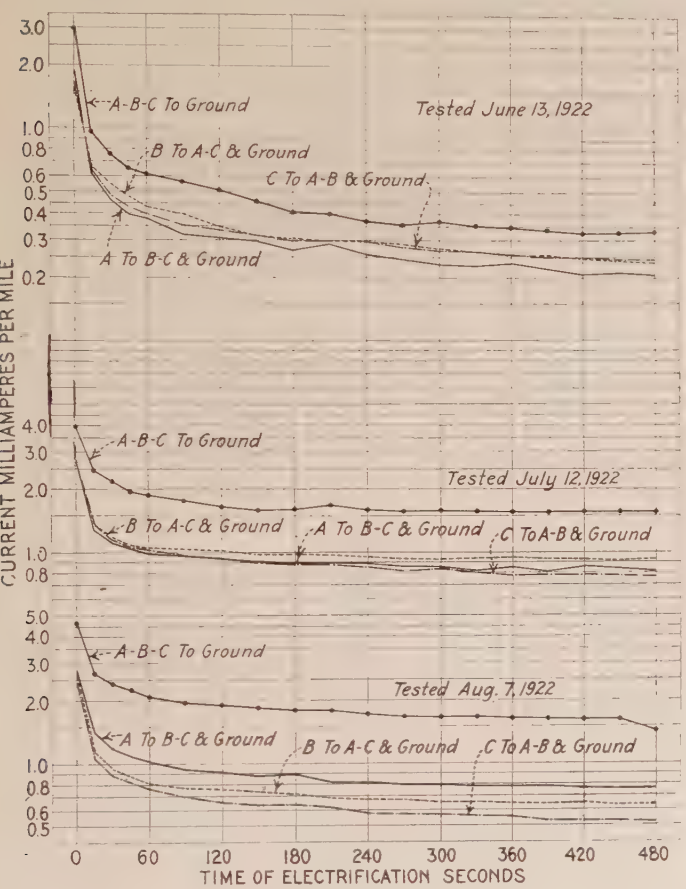

Fig. 10—Current-Time Curves

At 15,000-volts electrification by kenotron feeder 345; oprating voltage 13.2 kv.; $\frac{7 \times 7 \text{ in.}}{32}$ impregnated paper insulation: 3 × 250,000 = cir. mil. conductors; feeder length 12,924 ft.

to cables operating at nominal pressures other than 6000-volts.

However, due to the fact that the total current from the kenotron into the cable consists of three components, viz. capacity current, absorption current, and leakage current, and since these vary in magnitude according to the length and condition of insulation of the cable a wide variation in the amount of current to be measured when testing different classes of cables may be expected to occur. Accordingly, refinements in the method and apparatus used for reading the current values may be desirable and even necessary for some cables. Also, since the shape of the current-time curves is indicative of the condition of the insulation, as has been shown, it is evident that any refinements possible in obtaining accurate test values will be of aid in detecting an impending fault at an earlier stage of its development than is now possible.

Conclusion

The material which has been presented leads to the conclusion that the method of testing here outlined provides a means by which it is feasible to determine the operating condition of paper insulation on high-voltage alternating-current transmission cables. It will also be readily seen that this scheme of testing conforms with the desired characteristics of a routine test method which were previously outlined.

Since the major part of this investigation has been carried out on cables which were known to have been manufactured prior to the production of the present day low-dielectric-loss, high-efficiency cable it is believed that a large amount of supplemental information should be obtained.

In the following there are listed a number of points which should be investigated further. They readily arrange themselves in two divisions, viz. practical and theoretical.

Practical Problems

1. Determine characteristic current-time curves for high-efficiency cable.
2. Make mechanical study of faults detected by kenotron.
3. Determine feasibility of extending use of kenotron to actual development of fault, without recourse to alternating-current test sets.
4. Ascertain necessity for more sensitive indication of impending failure than indicated by inversion of current-time curves.
5. Determine what, if any, necessity exists for a source of energy for the operation of the kenotron, independent of the station bus supply.

Theoretical Problems

1. Ascertain what, if any, modifications of shape or magnitude, of the current-time curves results from changes in the rate of electrification.
2. What, if any, modification of the current-time curves results from electrifying cables to different ultimate potentials?
3. Determine what modification of the current-time curves results because of different operating temperatures of the cables.
4. Make comprehensive study of wave shape of the current and voltage as supplied by the kenotron under test conditions.
5. What relation, if any, exists between milliamperes per unit of length and condition of cable insulation?

6. Determine significance and effect of flashover of the protective sphere gaps, provided on kenotron sets, upon this method of testing.

It is believed the results of investigations now in progress, along some of the lines indicated, will prove of great value.

The assistance that has been received, in the preparation of this paper, from Dr. Steinmetz, Mr. J. L. R. Hayden and Mr. E. E. F. Creighton, of the General Electric Company, and Mr. H. P. Liversidge, Assistant Chief Engineer of The Philadelphia Electric Company, is gratefully acknowledged. We also wish to express our appreciation of the efforts of those in the Station Operating Department and Laboratory Division of The Philadelphia Electric Company who assisted in obtaining the information desired.

Power Absorbed in Making a Barrel of Portland Cement

BY S. H. HARRISON

Associate, A. I. E. E

Chief Engineer, Vulcanite Portland Cement Co., Easton, Pa.

Review of the Subject.—*During the year 1920 the total production of Portland Cement in the United States was 99,694,000 barrels. Of this amount 25,197,000 barrels or, approximately, 25 per cent were made in the Lehigh District, or in the plants located in Eastern Pennsylvania, and New Jersey.*

On account of the industrial depression the production for the year 1921 was somewhat lower than that stated above.

If we assume that one barrel of cement is made with an expenditure of energy amounting to 16 kw-hr., it will be seen that there is required in the 20 mills which comprise the plants in the Lehigh district, an aggregate load of approximately 46,000 kw. to make the 25,197,000 barrels for one year.

These figures are interesting in view of the fact that so much thought is being expended today on the superpower system.

It is well to remember, however, that about 80 per cent of the total energy required to make a barrel of Portland cement can be obtained by utilizing the heat in the waste gases from the rotary kilns; the balance, or 20 per cent, will have to be either generated by ordinary methods, or purchased from power companies.

At the present time comparatively few cement plants are utilizing the waste heat from the rotary kilns, but from the success which has been obtained by those who installed the waste heat system, there is every indication that before long the major portion of the power required in cement plants will be obtained from the heat now carried off in the stack gases.

* * * * * *

BEFORE entering into the subject of power absorbed in making a barrel of Portland cement, it might be well to describe in a very brief manner the process by which the cement is made.

In the Lehigh Valley district of Eastern Pennsylvania the cement rock which is known by geologists as argillaceous limestone is first quarried, and then transported to crushers, where it is reduced to a size convenient for drying. The drying of the rock is usually done in a rotary drier, which consists of a sheet-iron cylinder about 5 ft. in diameter by 60 ft. or more in length, supported on rollers.

The axis of the cylinder is inclined to the horizontal at a pitch of approximately ¾ in. to the foot, so that the slow rotation of the drier (about four rev. per min.) causes the broken stone gradually to find its way to the lower end where it is discharged, and then conveyed to the raw material pulverizing department. It is usually necessary, before drying the stone, to correct the lime content by adding a certain percentage of high carbonate limestone.

The raw mixture in a roughly ground and dried condition is then pulverized. After having been pulverized to a fineness so that approximately 85 per cent will pass a sieve having 200 meshes to the linear inch, or 40,000 meshes per sq. in., it is taken to the kiln department where it is fed to the rotary kilns.

The vast majority of kilns in this country are fired with pulverized coal. In a few instances, notably on the Pacific Coast, fuel oil is used for firing the rotary kilns.

The modern rotary kiln is a large sheet-iron cylinder about 8 ft. or more in diameter by 100 ft. to 125 ft. in length. Where the length of 200 ft. is employed, the diameter is in the neighborhood of 12 ft. The cylindrical shell is lined with a highly refractory fire brick.

The finely ground raw material is fed in at the upper end of the kiln, and since the axis of the kiln is inclined horizontally at a pitch of from ⅜ m. to ¾ m. to the foot, the slowly revolving shell causes the pulverized material gradually to work forward, and at the same time it comes in contact with the flame of the pulverized fuel.

Three operations take place in connection with the pulverized rock:

1. Moisture in the raw material is expelled, and the mass of ground rock raised in temperature.
2. Carbonic acid gas is expelled from the rock.
3. Fusing of the lime, silicates and aluminates which completes the burning process.

It might be well to state at this point that for every 600 lb. of raw material fed into the kiln 376 lb. of burned clinker is discharged from the end of the kiln. The

Presented at the Lehigh Valley Section of the A. I. E. E., Nazareth Pa., November 10, 1921.

balance (224 lb.) is lost as CO_2, dust and moisture. The moisture content for raw material is very low in the dry process of manufacture.

The burned or calcined rock after it has been cooled is mixed with a small percentage of gypsum, and then reduced to a powder, the fineness of which is about 80 per cent passing a 200-mesh sieve. This is the Portland cement of commerce.

The gypsum is added to retard the process of hardening when the cement is mixed with water for the mason's use. Without the retarding process the cement would set too quickly, and in all probability harden under the mason's trowel. The setting time is changed by the addition of the gypsum from a few minutes to several hours.

This is a hasty sketch of the process of the manufacture of Portland cement as generally employed in the United States, with the exception that in some instances, notably in the Middle West, the wet process is used. The materials in this case are usually marl and clay; they are mixed in a wet condition, ground in a wet condition, and fed to the rotary kilns in the form of a slurry. In some localities a high-carbonate limestone is mixed with the necessary amount of shale, or clay, to bring the percentage of the various constitutents in the raw material up to the required amounts.

One of the principal items which enters into the cost of manufacture of a barrel of Portland cement is the item of power cost. It is an index of the mechanical efficiency of the plant, and if the method of driving the machinery in the different departments of the mill is by means of electric power, an analysis of the power cost can readily be made. The results of tests, which will be given later, represent measurements which were carefully made; in no case were they "dress parade" tests, but tests covering considerable periods of time ranging from one week to one year.

It might also be stated that the instruments were carefully calibrated. The results given then are the results obtained from everyday practical mill operation.

In the analysis of the cost of manufacture of a barrel of Portland cement, the following subdivisions are usually made:

1—Quarrying, which in addition to other items includes the cost of transporting the stone from the quarry to the crushers.

2—*Raw Grinding,* including the cost of expelling the moisture from the rock; *i. e.* cost required to operate the drying machinery, in addition to pulverizing the raw material.

3—*Fuel Mill Charge,* which generally means the cost of handling and preparing the fuel used in the rotary kilns, and delivering this fuel to the kilns.

4—*Burning,* which includes the delivery of the calcined rock or clinker to the clinker storage department, in addition to the charge for fuel.

5—*Clinker Grinding, or Finishing,* which in addition to pulverizing the clinker, includes the cost of delivering the resulting cement to the bins in the warehouse.

6—*Packing and Shipping.*

7—*General Expense,* which includes all costs of a general nature that cannot be properly charged to any of the previously mentioned departments.

TESTS

In the tests which follow the analysis of the expenditure of power is along these lines. Fig. 1 shows this graphically.

The first case is that of a plant employing the wet process of manufacture. The clay is received at the

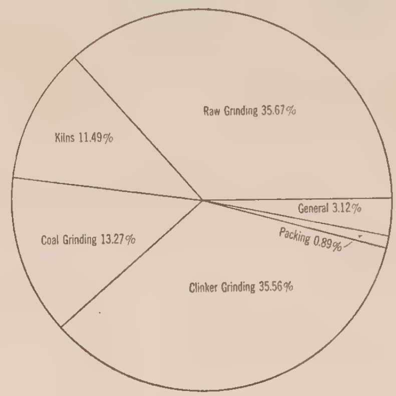

FIG. 1.

plant as mud. Limestone in the form of quarry screenings is added, and the wet mixture ground in a wash mill, kominuters and tube mills, and then fed to the kilns in the form of a slurry.

The electric energy used is 440-volt alternating-current, three-phase, 60-cycle.

Sixty-eight per cent of the power used is purchased from a power company, the balance, 32 per cent, is generated at the plant. The average full load was 1230.3 kw., or 1648.7 h. p., at a power factor of 83.5 per cent. The capacity of the plant is 1800 bbl. of Portland cement per day of 24 hr. although during the test the average production was 1500 bbl. per 24 hr. The rated motor capacity was 1927.5 h. p. The motors in the mills were then operating at 76.5 per cent of their rated capacity, assuming a motor efficiency of 90 per cent. The power consumption in kilowatt-hours per barrel of cement was made up as follows:

Per cent		Kw-hr.
35.67	Raw grinding, including clay wash mill.	5.156
11.49	Burning	1.660
13.27	Fuel mill (pulverizing coal)	1.916
35.56	Clinker grinding	5.138
0.89	Packing	0.128
3.12	General, including shops	0.450
100.00	Making a total of	14.448

It should be noted in this case the clay shovel is operated by steam, and a steam locomotive pulls the

loaded cars from the clay banks and quarries to the mill.

To be exact the power required for this service should be added to the 14.448 kw-hr. it is, perhaps, safe to say in this particular plant one barrel of Portland cement is made with the expenditure of 15 kw-hr. and considering the small output of the plant, in question, this figure is low, and indicates efficient mechanical operation.

The second case is that of a plant having a daily rated capacity of 3500 bbl., but which during the test had an average daily production of 2950 bbl.

The process used was the dry process, the raw materials being limestone and clay. The raw mixture was composed of 92 per cent limestone, and 8 per cent clay, 625 lb. of raw material making one barrel of finished cement of approximately 380 lb.

The electrical power used was 440-volt alternating current, three-phase, 60-cycle, and the average full load was 3056 kw., or 4095 h. p. at a power factor of 81.5 per cent.

All electrical power is generated at the plant. The rated motor load was 4190 h. p., so that the motors were operating at about 87.7 per cent of their rated capacity.

The analysis of the power absorbed in making a barrel of cement is as follows:

	Kw-hr.	Per cent
Quarry	0.318	1.84
Stone crushing—drying	2.094	12.13
Clay digging—drying	0.273	1.58
Raw grinding	5.398	31.30
Kiln (burning)	1.906	11.02
Coal grinding	1.347	7.81
Clinker grinding	5.578	32.36
Packing	0.287	1.66
General (shops)	0.050	0.30
	17.251	100.00

Some interesting figures obtained at this plant were as follows: It required

1.106 kw-hr. per ton of stone quarried.
7.283 kw-hr. per ton of stone, crushed, dried and stored.
10.910 kw-hr. per ton of clay dug.
17.274 kw-hr. per ton of raw material obtained.

The third case is that of a plant having a daily rated capacity of 6000 bbl. During the test, which was of seven days duration, the average mill output was 5650 bbl. The dry process of manufacture was used.

The electric power was direct current, 250 volts. The power absorbed in making one barrel of Portland cement was as follows:

	Kw-hr.	
RAW GRINDING:		
Crushers	0.375	
Storage, drying and pumps	0.568	
Raw grinding	5.029	5.972
Kilns	0.881	
Coal grinding	1.045	
Clinker grinding	5.992	
Packing	0.242	8.160
GENERAL:		
Lights	0.233	
Air compressor	0.031	
River pump	0.102	
Machine shop	0.018	0.384
	Kw-hr.	14.516

The fourth case is that of a wet process plant using marl and clay. The daily capacity of the plant is 2250 bbl., but during the test the plant was operating at a daily rate of 1845 bbl.

The electric energy was alternating current, three-phase, 60-cycle, and the average load was 1165 kw. or 1561 h. p. The rated motor capacity was 2012.5 h. p., so that the motors were then operating at about 69.8 per cent of their rated load. The power factor was 66.4 per cent.

The distribution of the power per barrel of cement is as follows:

	Kw-hr.		Per cent
Wash mill	0.831		
Raw grinding	1.715	2.546	23.82
Kiln	1.980		18.52
Coal grinding	1.831		17.15
Clinker grinding	4.209		39.40
Packing	0.119		1.11
	10.685		100.00

This figure does not include power required to operate locomotive, steam dredge, and mill lights. These items would, probably, bring the total figure up to about 12 kw-hr., which is very good.

The power required to operate a wet process plant is somewhat lower than that required to operate a dry process plant.

The fifth case represents a 3000-bbl. plant using the dry process of manufacture.

Electric energy is 550-volt alternating current, three-phase, twenty-five-cycle, and power is distributed as follows:

	Kw-hr.
Quarry and raw grinding	5.492
Kilns (burning)	0.961
Coal grinding	0.980
Clinker grinding	5.385
Packing	0.162
General	0.212
	13.192

Another dry process plant using 550-volt alternating current, three-phase, 25-cycle, is making a barrel of Portland cement with the expenditure of only 13.707 kw-hr.

These last two figures represent excellent operating conditions. About 16 kw-hr. per barrel of cement manufactured may be taken as a very good average figure.

In addition to the energy consumed in the mechanical processes of Portland cement manufacture, *i. e.* conveying, crushing, pulverizing, packing, etc., large amounts of energy must be used in the form of direct application of heat; for instance, about 63,000 B. t. u. are utilized, or rather employed, for drying the necessary stone to make one barrel of Portland cement, and in addition to this about 1,260,000 B. t. u. are required to calcine the necessary amount of pulverized raw material to make one barrel of the finished product.

In all, 1,323,000 B. t. u. are required per barrel for direct heat application. Of the 1,260,000 B. t. u. per barrel used in the rotary kilns, not more than 25 per cent of this figure performs a useful function in the kiln. The remaining 75 per cent is lost in radiation,

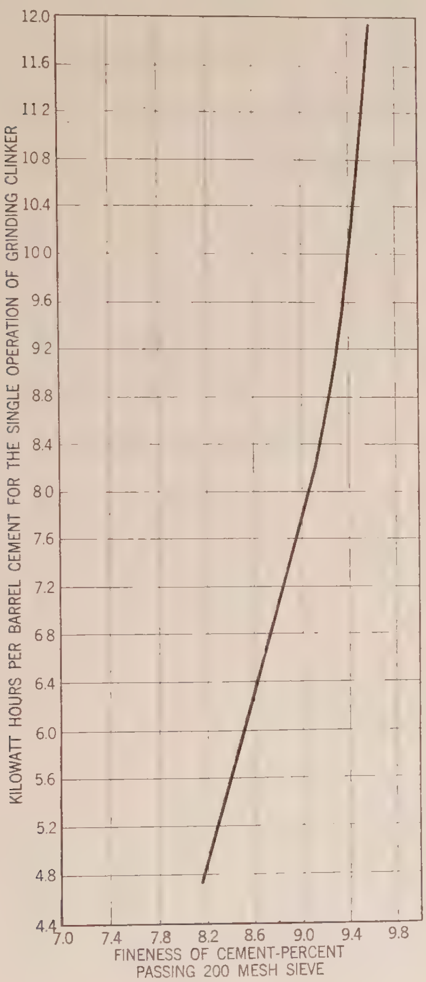

FIG. 2

or heat conduction and convection, heat carried off by the waste gases, and heat carried away by the clinker discharged from the rotary.

Of late, considerable progress has been made in reclaiming some of this waste heat. The most notable progress being in the utilization of the heat contained in the stack gases. In this case the heat is used for the generation of steam in specially designed boilers.

Progress is also being made in utilizing some of the heat in the discharged clinker by causing it to preheat the air used in the combustion of the fuel in the kiln, and lastly, there is the most difficult of all the kiln problems to reduce the amount of heat radiated from the kiln shell; here, too, progress has been made, but not to the same extent as in other directions.

Fig. 1 shows diagramatically how the consumption of power is distributed in the various departments of a cement mill. It is, perhaps, well not to compare different plants on a department percentage basis, but on the basis of actual kw-hr. consumed in each department.

It has been found that there is very little difference in the kw-hr. consumption in the actual pulverizing of materials in the different plants irrespective of the type of machinery employed. Just so much energy is necessary to reduce the materials to their finely pulverized condition, no matter what type of mill is used. In every case, however, the power absorbed in grinding the material increases greatly with the fineness of the finished product.

Fig. 2 shows in a general way just how the power varies with the fineness produced in grinding Portland cement clinker to finished Portland cement. The curve represents the average results of tests made with a number of mills of various types. Of course, each plant will have its own particular curve of fineness power, but in all cases the increase in power is quite rapid when compared with the increase in fineness of the product.

A study of the curve shown in Fig. 2 is interesting. It shows that if we increase the fineness of the finished product—say, from 82 per cent to 88 per cent—there will be absorbed an aditional 2.10 kw-hr. per barrel ground, assuming, that the mill output is the same. For a plant making, say, 3000 bbl. in 24 hr. there would have to be added 263 kw. in motive power for the single operation of grinding the clinker. It can be readily seen how rapidly power consumption mounts for a slight increase in the fineness of the finished product.

THE USE OF LAMPS IN BAKE OVENS

Sometimes incandescent lamps are operated in places where an excessive temperature is maintained. An example of such a case is found in bake ovens where light is needed to inspect the contents of the oven. These ovens usually operate with an interior temperature of from 425 to 450 degrees Fahrenheit. Inasmuch as this temperature is too high for the ordinary basing cement and solder, special lamps have been developed for use in such locations. These lamps are given special treatment in such matters as glass, basing, cement, solder, exhaust, etc. to enable them to operate satisfactorily in surrounding temperatures of from 425 to 450 deg. Fahr.

The Wave Antenna

A New Type of Highly Directive Antenna

BY HAROLD H. BEVERAGE, CHESTER W. RICE, and EDWARD W. KELLOG
of the Radio Corporation of America — Assoc. A. I. E. E. of the General Electric Co. — Assoc. A. I. E. E. of the General Electric Co.

Review of the Subject.*—A small bungalow in a grove of oak trees just outside of Riverhead, Long Island, with a line of poles along a country road, carrying two copper wires, and ending by a stream nine miles southwest of Riverhead,—this in brief describes the Atlantic coast "ear" of the Radio Corporation of America, where the wireless messages from England, France, Germany and Norway are received, disentangled, amplified, converted into current of telephonic frequency and automatically relayed over telephone circuits to the Broad St. Office in New York, where operators take the messages by ear, or automatic recorders mark the dots and dashes on tape.*

The present paper deals with the two copper wires on the line of poles, for they constitute the wave antenna which has not only marked a distinct advance in the reduction of interference and "static," but because of its aperiodic nature and effectiveness as an energy collector, has made possible the sumultaneous reception of a large number of messages by one antenna, and the automatic relaying of the messages over land wires.

The use of two wires is not an essential feature of the wave antenna but permits flexibility in the location of the receiving station. In its elementary form the wave antenna consists of a straight horizontal conductor. (See Fig. 10) of the order of a wave length long, parallel to the direction of propagation of the desired signal, with the receiving circuit located at the end farthest from the sending station and with the end nearest the sending station grounded through a resistance of the proper value to practically prevent reflections. Under these conditions the desired signal waves produce comparatively feeble currents at the end nearest the sending station and strong currents at the receiver end, while disturbances coming from the opposite direction cause feeble currents at the receiver end and strong currents at the end farthest from the receiver (nearest the transmitting station) (See Fig. 2). This comparative immunity of the receiving set to disturbances coming from a direction opposite to the desired signal is lost if reflections are permitted to occur at the end farthest from the receiver. The growth of current in the direction of travel of the space wave depends on the velocity of propagation of waves on the antenna in comparison with the velocity of the space waves, the received current being strongest if the two are equal. If the characteristic wave velocity on the antenna is less than that of the space waves (or less than the velocity of light) increasing the length of the antenna increases the received current up to a certain point, after which further increase in antenna length reduces the received current. The length for maximum signal depends on the velocity ratio and wave length. The slower the antenna or the shorter the wave length received the shorter the length for maximum signal. It is very frequently the case, however, that the best directive properties are obtained with an antenna longer than that which gives the strongest signal.

The effect of the space wave is to produce in the wire a signal frequency electromotive force which affects the different parts of the antenna progressively as the space wave passes over the line. On this basis the received current can be calculated in terms of the frequency and intensity of the induced electromotive force, the direction of the space waves and the length and electrical constants of the antenna. By assuming the direction to be changed while all other factors remain the same, and calculating the relative value of received current for various directions of signal wave, we can determine the directive properties of the antenna. The result is best shown by means of a polar directive curve. For each assumed direction for which the received current has been calculated, a radius is drawn, with length proportional to the received current. The curve drawn through the ends of these radii is known as the directive curve for the antenna. Directive curves are given (Figs. 35 to 41) which bring out the effects of antenna length, relative to the wave length, velocity of propagation, and line attenuation. The directive curves are for the most part drawn with the maximum radius taken as unit length, since this makes comparisons of directive curves easier. In general, it is found that moderate line losses are not appreciably detrimental to the directive properties of the antennas, while the fact that velocities obtainable with unloaded lines are materially below that of light, results in an actual improvement in directive properties in most cases. As a rule the longer the antenna the sharper its directive curve. While it is possible to obtain fair directive properties with antennas less than a half wave length long, this length is considered about the shortest that can be recommended.

By a process of balancing, it is possible to produce a "blind spot" or direction of zero reception, at any angle more than 90 deg. from the signal. One method of obtaining this result is by producing reflections of certain phase and intensity at the end opposite to the receiver. Reflections at the receiver end of the antenna, on the other hand, do not alter the directive properties of the antenna.

Experimental work thus far has given a qualitative check on the theory and calculations of the wave antenna, and it is hoped that further observations and measurements will shortly be made. Experimental data on wave front tilt, on which the action of the wave antenna depends, is especially meagre.

Data on wave velocity and line losses on an existing antenna can be obtained by means of a radio frequency oscillator and one or two hot-wire milliammeters. Measurements taken by the writers show much higher attenuation and lower velocities for ground return circuits than for metallic circuits. Ground resistance explains this effect. The mean depth of return currents at the longer radio wave lengths appear to be of the order of several hundred feet. The more wires in multiple in the antenna, the lower the velocity and the higher the rate of attenuation (See Fig. 66 and 68).

Reduction of atmospheric disturbances or "static", has probably received more attention from experimenters than any other one phase of radio reception. Of the various lines of attack none has been more fruitful than the employment of directive receiving systems. Every increase in directivity has resulted in an improvement in stray ratio. The wave antenna carries the principle farther than any previous type. Conditions on the eastern coast of North America are especially favorable for taking advantage of differences in direction, for the European stations are to the northeast while the predominating direction of static is from the southwest.

Various practical engineering problems in connection with the wave antenna, including its application to short wave reception, are discussed toward the close of the paper.

HISTORICAL

THE wave antenna is a long horizontal antenna and therefore belongs to the class of antennas usually referred to as ground antennas, of which it is an outgrowth.

The first work with long horizontal antennas appears to have been done in the pioneer days of radio by Marconi[1], Braun[2], Secher[3]. A short historical sketch

Presented at the Midwinter Convention of the A. I. E. E., New York, N. Y., February 14-17, 1923.

1. Marconi, English Patent No. 12039, 1896.
2. F. Braun, D. R. P. No. 115081, 1898.
3. E. Secher, *Phy. Ztschr.* 4, 320, 1903.

of ground antenna work is given by Zehnder[4] who was also an early worker in this field.

More recently Kiebitz[5] has studied the transmission and reception using certain forms of ground antennae. A discussion of the operation has been given by Burstyn[6]. Further experiments and comments on the operation of ground antennae are given by Kiebitz, Burstyn, Hansrath, Mosler[7].

In this country early work was done by Clark, Rogers and Taylor. This work has been recorded in the classical papers by Taylor[8].

Alexanderson's[9] barrage receiver made use of ground antennae and may be considered as the starting point of our work.

The capabilities of the wave antenna were discovered through work done by Beverage in studying the properties of long ground antennas, of the order of a half wave length or more long, in which he discovered that under certain circumstances they showed marked unidirectional properties. One of his antennas consisted of a No. 14 B & S rubber covered wire approximately six miles long laid on the scrub oak and sand of Long Island from Eastport to a point near Riverhead. This northeasterly direction was chosen in order to best receive the European stations. The antenna is pictured diagramatically in Figure 1.

With the receiving set connected between the antenna and ground at the Eastport end and with the Riverhead end grounded, Beverage observed strong signals from Europe, but when the conditions were reversed and the receiver was inserted at Riverhead the European signals were very weak and the static and stations to the southwest were strong. This marked unidirectional property of the antenna was found only when the end opposite to the receiver was grounded.

Fig. 1

Beverage next investigated the effect of antenna length by listening in series with the antenna at different points along the antenna. The receiver was mounted in a Ford truck and trips were made back and forth along the antenna, stopping to listen at approximately every mile. By this process the observations given in Fig. 2 were obtained.

In commenting on these observations Beverage's log reads - - - - - "It is evident that the antenna is too long for maximum reception at the S. W. end. It may be due to the fact that the velocity of the current in the wire is considerably slower than the velocity of light, and the currents from remote parts of the antenna lag in phase behind currents from parts of the antenna near the receiver. If so, condensers, distributed along the line, could be used to increase the velocity of currents flowing in the wire and make the velocity the same as the velocity of light." By inserting series condensers in the line Beverage found that he could shift the location of the points at which the signal maxima occurred and thus utilize longer antennas.

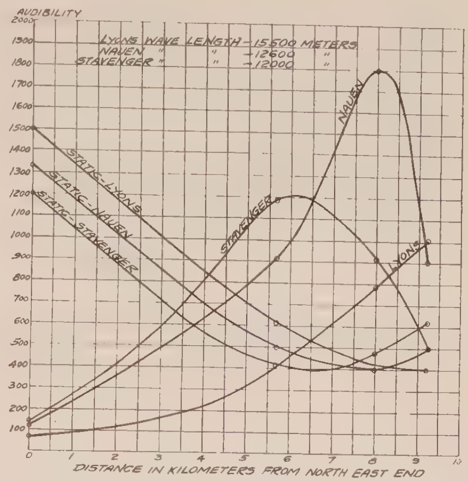

Fig. 2—Growth of Signal Currents in Long Horizontal Antenna

At about this point in the work Mr. Alexanderson called Rice's attention to Beverage's important discovery. Rice and Kellogg, before learning of the results of Beverage's work, had concluded on purely theoretical grounds that a long horizontal antenna, pointing in the direction of a sending station, would constitute a unidirectional receiver provided the receiver were placed at the end of the antenna remote from the sending station, while the end nearest the transmitting station was grounded through a non-inductive resistance, equal to the surge impedance of the antenna. If open or dead grounded at the end nearest the transmitter, reflections would occur, and the antenna should show bidirectional properties. Rice explained this theory of the operation to Mr. Alexanderson, suggesting that the necessary damping required to make the antenna unidirectional was due to the resistance of the ground connections combined with the high attenuation to be expected in an antenna of No. 14 B & S rubber covered wire lying on the sandy soil and bushes.

At Mr. Alexanderson's request, Rice joined Beverage at Eastport, and a study was made of the properties of the rubber covered lines by means of an oscillator. They also made listening tests which indicated that some resistance, in addition to the ground resistance, was best for unidirectional effects.

The use of the oscillator made it possible to determine

4. L. Zehnder, *Jahrb. d. drahtl Tele.*, Vol. 5, 1911, p. 594.

5. F. Kiebitz, *Jahrb. d. drahtl Tele.*, Vol. 5, 1911, p. 349, Vol. 6, 1912 p. 1 and p. 554. Also *Electrician*, Vol. LXII, p. 972 and Vol. 68, 1912 p. 868, 936, 978, 1020.

6. W. Burstyn, *Jahrb. d. drahtl Tele.*, Vol. 6, 1912, p. 10 and 333.

7. *Jahrb d. drahtl Tele.*, Vol. 6, 1912, p. 359 and p. 570.

8. A. Hoyt Taylor, I. R. E., Vol. 7, 1919, p. 337 and p. 559.

9. E. F. W. Alexanderson, I. R. E., Vol. 7, 1919, p. 363.

the characteristics of the lines with considerable accuracy. Two methods were followed. The first consisted in measuring the input current to the line as the frequency is varied. This gives a series of maxima and minima as the line passes through successive modes of oscillation. If the far end is open, current maxima will

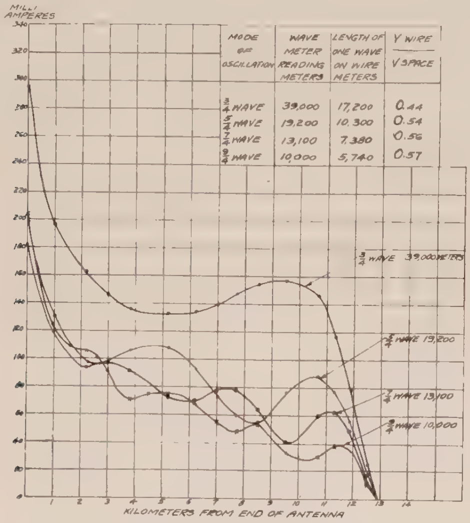

FIG. 3—OSCILLATOR TESTS OF RUBBER COVERED ANTENNA WIRE. CURRENT DISTRIBUTION WITH FAR END OPEN

occur with 1/4, 3/4, 5/4, etc. standing waves on the line, while if the far end is grounded the current maxima correspond to an even number of quarter wave-lengths. From this data the velocity on the line may be computed.

The second method of testing consisted in supplying

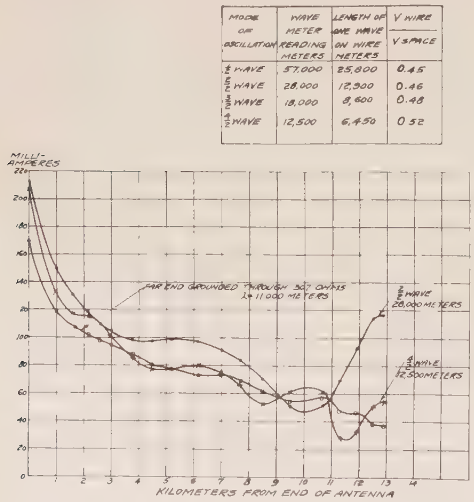

FIG. 4—OSCILLATION TESTS OF RUBBER COVERED ANTENNA WIRE. CURRENT WITH AND WITHOUT DAMPING RESISTANCE

the line with a constant current from the oscillator and measuring the current at intervals along the line with a hot-wire milliammeter. Figs. 3 and 4 show typical curves obtained in this manner. The high attenuation and low velocity characteristic of lines of this type were brought out, and the irregularities of the current distribution curves showed the effects of changes in line constants which would be expected in view of the fact that portions of the line lay on practically bare ground, and other parts were well above ground.

Further studies were made of the effects of series condensers. Fig. 5 compared with Figs. 3 and 4 shows the increase in velocity brought about by the insertion of series condensers. While it was shown that the effective velocity could be raised to the desired value,

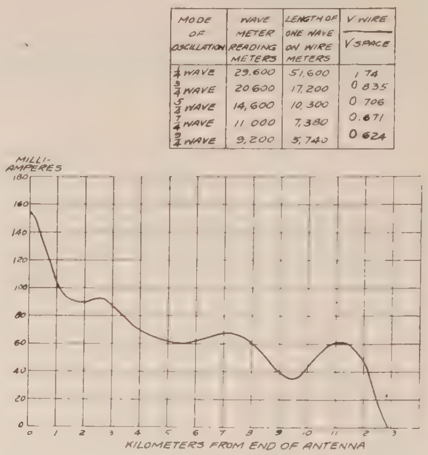

FIG. 5—OSCILLATOR TESTS OF RUBBER COVERED ANTENNA WIRE WITH TWENTY-TWO 1/10 MICROFARAD CONDENSERS IN SERIES. CURRENT DISTRIBUTION WITH FAR END OPEN

the limit of useful length was now set by the high attenuation.

A midwinter blizzard put a stop to further tests on the rubber covered lines, but sufficient data had been gathered to warrant confidence in the theory of the wave antenna and indicate its value. Acknowledgment should be made of the assistance during this work given by Mr. P. S. Carter and Mr. R. D. Greenman.

THE NEW RIVERHEAD ANTENNA

Since the full realization of the possibilities of the

FIG. 6

wave antenna called for a line of high velocity and low attenuation, and free from points of reflection, the next logical step was to build a high grade line of the best possible type. Bare copper wire on poles was recommended and Mr. Alexanderson, who had enthusiastically followed the work at Eastport, had the line constructed by the Radio Corporation. Work was begun as soon as the frost was out of the ground and in June the line was ready for experimental use. Fig.

6 shows a photograph of part of the line. A flexible type of line construction was adopted which would make it possible to try numerous experiments such as a series of loops or series of verticals connected through a transmission line, etc. Two cross arms were provided, one at a height of 18 feet and the other 30 feet above ground. The upper arm carried two No. 10 B & S copper wires and the lower arm four similar wires. All lines were broken every ten poles, and down leads were

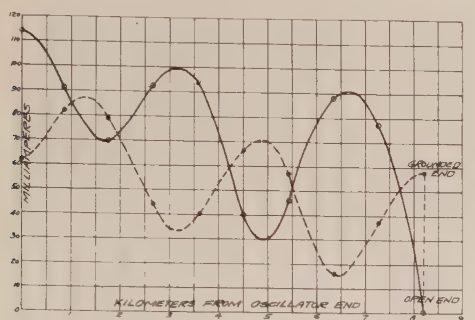

FIG. 7—OSCILLATION TESTS OF RIVERHEAD ANTENNA. FOUR WIRES IN MULTIPLE. $\lambda = 9400$

provided so that connections could be readily changed. The line ran seven miles approximately southwest from Riverhead along an unfrequented sand road, and was later extended to Terrell River, making a total length of nine miles. The line is as straight as it was feasible to build it, and its direction is substantially in line with the principal European long wave stations, the reception of which was a matter of primary interest.

The first tests on the new line showed that the hoped

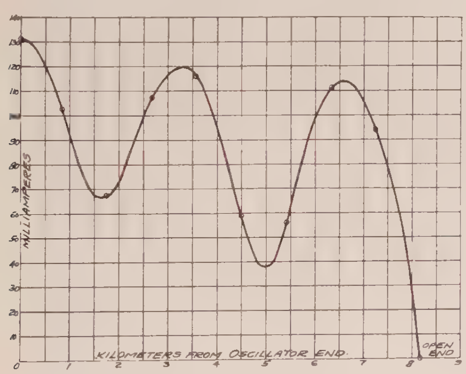

FIG. 8—OSCILLATION TESTS OF RIVERHEAD ANTENNA. TWO UPPER WIRES IN MULTIPLE. $\lambda = 7900$

for results had been realized. Instead of an optimum length of six or seven kilometers, the signals became stronger and stronger as the receiving set was moved toward the southwest, and the signal strength there was several times greater than had been obtainable with the rubber covered antennas. While the stray ratios observed on the rubber covered antennas had seemed excellent, the new antenna fully met our expectations of improvement.

Oscillator tests on the new antenna showed that the velocity was high and attenuation low compared with the rubber covered wires, and that it had no serious reflection points. Figs. 7, 8 and 9 show typical curves obtained with the new antenna. A comparison with similar curves, taken on the rubber covered ground wires, brings out the improved electrical properties.

The failure at the start to get good short circuit reflections when the far end of the line was grounded caused us to suspect that the high-frequency resistance of the grounds was much greater than we had estimated. These grounds were made with lines of iron wire laid in water. The substitution of copper wires removed this

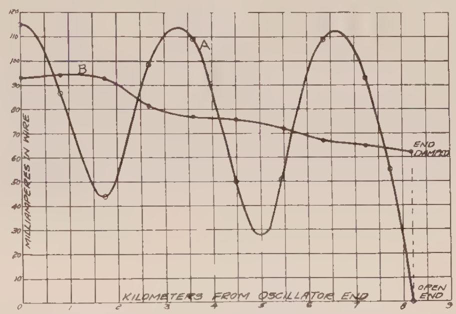

FIG. 9—OSCILLATOR TESTS ON RIVERHEAD ANTENNA. SINGLE UPPER WIRE, $\lambda = 7500$. *A* END OPEN. *B* END GROUNDED THROUGH 600 OHMS.

difficulty. The adjustment of resistance for unidirectional effects was now clean cut and in accord with the theory. A dead ground at the N. E. end gave as bad a stray ratio on the average as an open circuit.

EXPLANATION OF THE ACTION OF THE WAVE ANTENNA

The wave antenna in its simplest form consists of a horizontal wire of the order of a wave length long pointing towards the transmitting station, as pictured in Fig. 10.

When the signal wave reaches the end "*A*" an e. m. f. is induced in the horizontal antenna wire, due to the fact that the wave front is not perpendicular to the

FIG. 10—SIMPLE FORM WAVE ANTENNA

ground, but has a tilt forward of 1 deg. to 10 deg., depending on the wave length and character of ground. Thus, at the end *A*, a little wave starts to run down the antenna towards the receiving station, and if it travels with the same velocity as the radio wave in space, the space wave follows right along with it, supplying energy to it as it goes and building it up, until at the end *B* it has reached a magnitude many times that which it had at *A*. This is illustrated in Fig. 11 which shows a single wave at successive time intervals. If the velocity of the wave on the wire is not equal to the space

wave (velocity of light) interference effects develop, the wave on the wire building up for a certain distance and then decreasing in amplitude. The velocities on actual antennas, however, are nearly enough equal to that of light so that for considerable lengths the wave on the wire builds up as it would on a light velocity line.

A signal coming from the opposite direction to that which we have been considering, will build up a wave on the wire in a similar way, from a small value at B

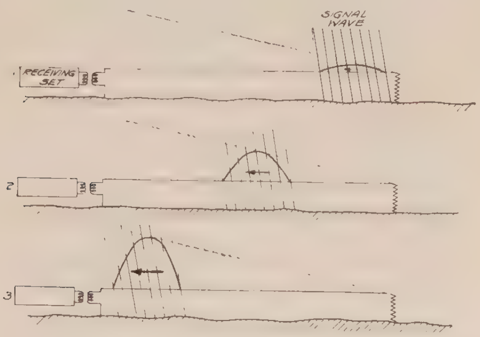

Fig. 11—Building Up of Wave on Wire as Space Wave Progresses

to a large value at A. If now the line were open or grounded at A, the wave would be reflected back over the antenna to the receiver end B, and would be heard. On the other hand, if we damp the end A in such a manner as to prevent reflections, the antenna becomes unidirectional. A non-inductive resistance, having the value $R = \sqrt{L/C}$ ohms, where L and C are the inductance and capacity of the antenna per unit length, constitutes a practically perfect damper.

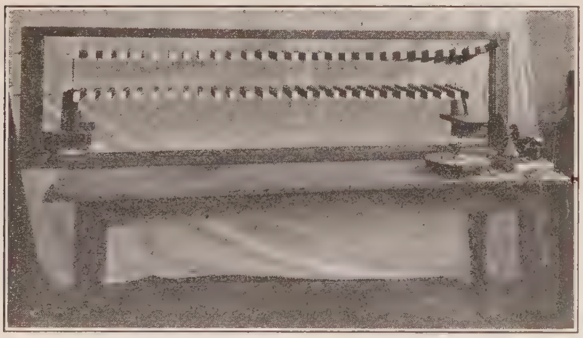

Fig. 12—Mechanical Model of Wave Antenna—Stationary View

Many mechanical analogies will occur to the reader, such as the building up of water waves in the direction of the wind. An interesting experiment is to run over thin ice. If you run at just the speed of wave propagation of the ice surface you can build up a larger wave. If you run too slow or too fast little effect is produced. To demonstrate the manner of building up of waves on a wave antenna, Rice and Kellogg built the mechanical model shown in Figs. 12 to 17. The upper line represents the space wave and the lower line the wave on the wire. Each line consists of a series of wooden sticks strung on a pair of small steel wires a half inch apart in the case of the lower line and an inch and a half apart in the upper line. The rockers of the upper line are loaded with lead. The inertia of the rocking stick is analogous to line inductance, while the elasticity of the connection between successive sticks is analogous to the capacity between the conductors of an electrical line. The velocity can be changed by varying the tension on the wires. The dashpots at the ends practically stop reflections. The upper line provides a means of imparting energy progressively to the different portions

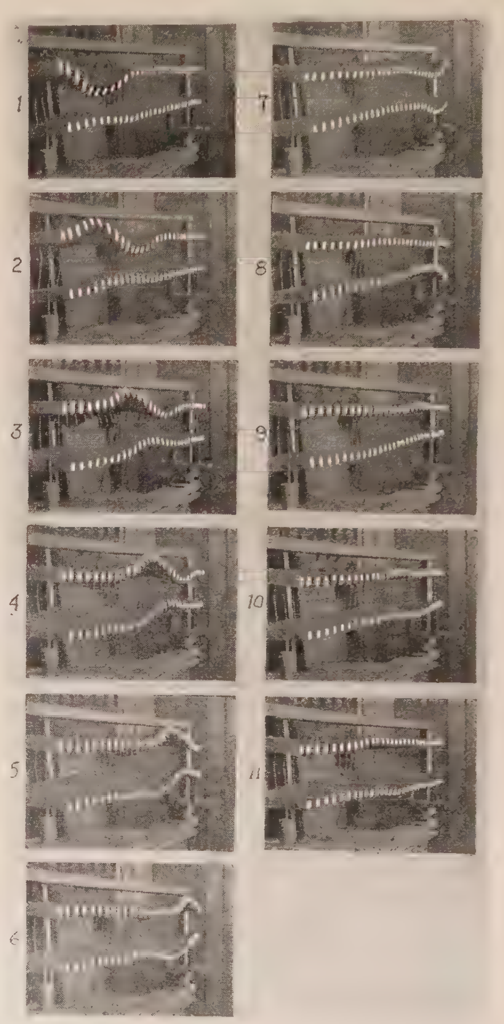

Fig. 13—Mechanical Model of Wave Antenna with End Damped

of the lower line, as a space wave imparts energy to the antenna line. A slight coupling between the two lines is supplied by light rubber bands stretched from short hooks on the upper sides of the lower sticks to corresponding hooks on the under side of the upper sticks. Waves are imparted to the upper line by moving one end by hand for an impulse or by a motor driven rocker for continuous waves.

Fig. 12 is a stationary view of the machine.

Fig. 13 shows a series of views taken with a moving picture camera, when an impulse is imparted to the

upper line. The growth of the wave on the lower line as it approaches the far end is readily seen. The wave on the lower line appears to pass off the end leaving the line practically stationary.

Fig. 14, compared with 13 shows the effect of removing the dashpot, thus permitting a free end reflection. We notice in these pictures a return wave which on reaching the near end, causes a movement of

Fig. 14—Mechanical Model of Wave Antenna with Free-end Reflection

the first rocker. This illustrates the loss of unidirectional properties if the end is not damped.

Time exposures, with continuous waves of constant amplitude supplied to the upper (space wave) line, bring out the amplitudes developed on various parts of the lower line, or the equivalent of current distribution in a wave antenna.

Fig. 15 shows the increase in amplitude on the lower line (antenna) as the waves progress from left to right. That the upper line carries practically pure traveling waves (*i. e.* has no return waves) is shown by the nearly uniform amplitude throughout its length.

Fig. 16 shows the effect of removing the dashpot at the right hand end of the lower line. Considerable movement at the extreme left end now appears, due to

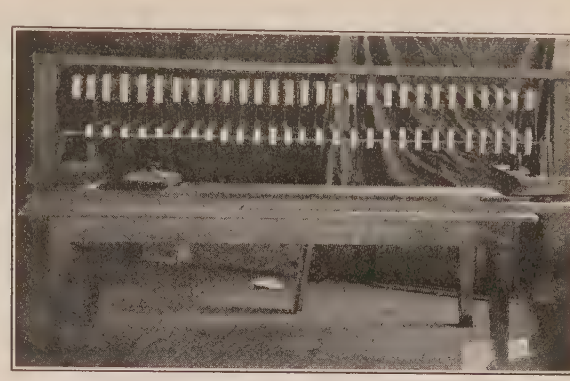

Fig. 15—Mechanical Model of Wave Antenna—Full Velocity, Building Up

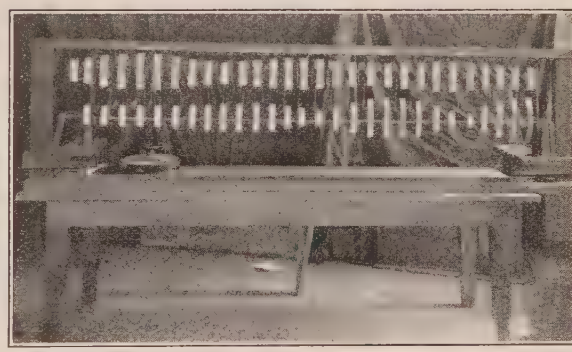

Fig. 16—Mechanical Model of Wave Antenna—Full Velocity, Reflection at End

Fig. 17—Mechanical Model of Wave Antenna—Slowed Down

the reflected wave. The forward wave (left to right) built up on the line, is very small near the left end, so we find the amplitude there nearly uniform, as would be expected with waves traveling in one direction only (right to left). On the other hand toward the right we see very clear standing wave effects, for here the for-

ward (left to right) wave has an amplitude more nearly equal to that of the return wave.

In Fig. 17 the right hand end is again damped, and the lower line has been slowed down by reducing the tension on the wires. This illustrates the building up and down of the waves on the antenna when its velocity is much below that of the wave in space.

Reduction to Practical Form

After the construction of the Riverhead antenna, considerable time was devoted to experiments of various kinds with the new antenna, tests and comparisons of different antenna arrangements, an oscillographic study of static, and tests of station apparatus.

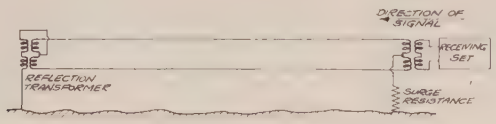

Fig. 18—Arrangement for Locating Receiving Set at Same End as Surge Resistance

Messrs. Beverage, Rice, Kellogg, P. S. Carter, R. D. Greenman and E. P. Lawsing participated. A number of practical developments were evolved in the course of this work.

The "Reflection Transformer" Circuit. In order that the receiving set might be located at the same end of the line as the surge impedance, thereby facilitating adjustment, the arrangement shown in Fig. 18 was proposed by Kellogg. The two wires work in multiple as an antenna, but act as a balanced transmission line to bring the signal currents back from the southwest end. This scheme obviates the use of extra wires for the return transmission line and thus avoids the problem of preventing detrimental effects of nearby conductors.

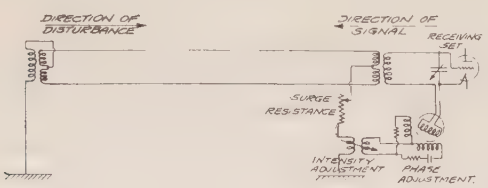

Fig. 19—First Balancing Circuit Employed for Obtaining Zero Reception from the Back End

When the primary of the "reflection transformer" was opened the receiving set was quiet, showing that the transmission line although it was not transposed, was not introducing any undesirable electromotive forces. Thus a horizontal loop receives neither static or signal.

Compensation for Back Wave. Beverage showed that while the resistance could be adjusted to give a minimum for static while listening to European signals, still better stray ratios were obtained by combining with the signal currents brought in over the transmission line, a small amount of the currents flowing to ground at the northeast end of the antenna. This he accomplished with a phase adjuster and intensity coupler of the type used by Mr. Alexanderson in the barrage receiver. The circuit arrangement is shown in Fig. 19.

The two long wave stations New Brunswick (13,600 meters) and Annapolis (16,900 meters) were of great assistance in making tests and adjustments. Either station could be entirely put out by using the phase and intensity adjustments of Fig. 19. It was found that when the adjustments were made for putting New Brunswick out, the stray ratio was best on the European stations whose wave lengths were near that of New Brunswick, and that when Annapolis was put out the adjustments were such as to give the best possible stray ratio for the longer wave European stations. In other words, the best stray ratio was obtained when the end conditions were adjusted to put out the image of the desired European station. If a light-velocity wave antenna is an exact number of half wave lengths long, the mathematical analysis shows that it is unidirectional provided the true surge impedance is connected between antenna and ground at the end nearest the transmitting station. This is illustrated in Fig. 29. Whether the true surge impedance is non-inductive or contains a capacity or inductive component will depend upon the

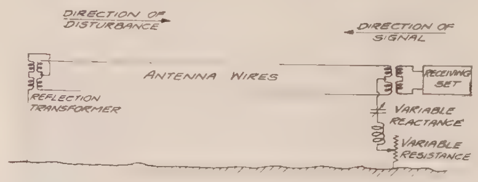

Fig. 20—Method of Balancing Back End Currents by Reflections from Damped End

characteristics of antenna and ground at the frequency under consideration. Kellogg pointed out that since the antenna was not an exact number of half wave lengths long, the back wave effect would prevent the antenna from being unidirectional even though the true surge impedance had been used, and it was for this reason that Beverage found that balances were required to obtain the best stray ratio. Another method proposed by Kellogg of supplying this necessary compensation was to insert a circuit consisting of inductance, resistance, and capacity in series in the neutral at the end nearest the transmitting station, as shown in Fig. 20. By adjusting the resistance and varying the capacity through the point where it tuned out the reactance of the coil, a wave of any desired intensity and phase could be reflected down the antenna to exactly compensate for the back wave effect and thus render the antenna unidirectional.

If only one station is to be received the circuit shown in Fig. 20 is as satisfactory as any that the writers have found. For reception of long wave stations an antenna output transformer was used having a step-down ratio of 200 to 10 turns, and having a complete iron magnetic circuit of about 3/4 square inch cross section, made of

0.0015 enamelled sheet iron of the kind developed for the Alexanderson alternators. The secondary was connected in series with the first tuned circuit of the receiving set.

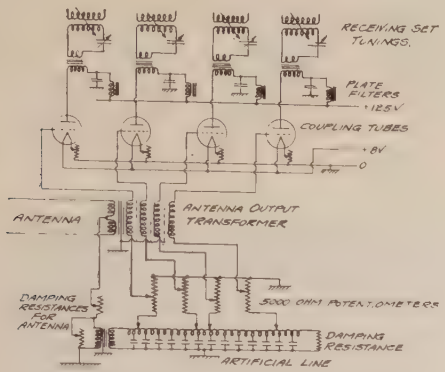

FIG. 21—MULTIPLEX RECEIVING SYSTEM

Multiplex Reception. The simultaneous reception of a number of stations was one of the next objects of our work. If the surge impedance is set at the best value for a mean wave length, and no finer adjustment of the back-end compensation is attempted, then it is only necessary to provide more secondaries for the antenna output transformer, Fig. 20. In order that one set should not sap too much energy from another, transformers were designed with very slight reaction between the secondaries. Some data were taken of the best resistance and reactance in the ground circuit, as a function of wave length, and networks were figured out which would give the desired impedances at the wave lengths of the stations which it was most important to receive. This system of multiplexing, however, did not appeal to the writers as the most satisfactory solution of the problem. A system was wanted in which all the adjustments for each station to be received could be made without reacting on the adjustments for the others. The arrangement shown in Fig. 21 was worked out, and proved entirely satisfactory. Each coupling tube feeds a receiving set, and the antenna output transformer and artificial line, with its sliding contacts and potentiometers, serve to impress the desired potentials on the grids of the tubes. Since the load is negligible there is no reaction between the different sets. Grounded shields between the secondaries of the antenna output transformer prevent electrostatic reactions. The desired component of the currents or potentials in the ground circuit can be obtained in any desired phase by moving the sliding contact along the artificial line, and in the needed intensity by adjusting the potentiometer. The artificial line has a characteristic impedance of about 400 ohms and reflections are prevented by a resistance of about this value. This results in a phase adjustment which gives practically constant intensity. Five thousand ohms potentiometers are used, and these constitute so small a load on the artificial line that the adjustment of any one does not appreciably alter the potential distribution on the line. The artificial line, damped as it is at the far end, acts as a practically pure resistance in the antenna surge impedance circuit. By adjustment of the series and shunt resistance boxes the antenna damping resistance may be set at the best average value, leaving only a small residual to be "cleaned up" by the artificial line adjustments.

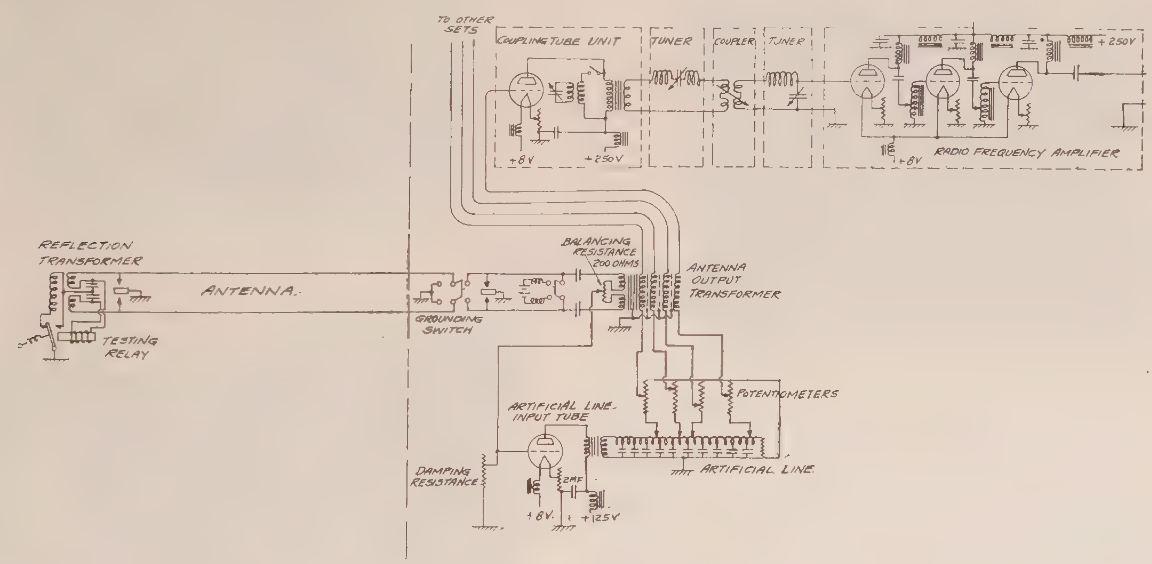

FIG. 22—WAVE ANTENNA CIRCUITS. PRESENT ATRANGEMENT

Fig. 22 is a more detailed diagram showing some changes which have been made since the original installation.

Shielded Sets. The aperiodic nature of the wave antenna and the success of the coupling tube multiplex system made it clear that there would be call for operating a number of receiving sets in the same building. The artificial line and antenna output transformer had been designed for operating four sets, but this was not necessarily the limit. In fact, later, when the new Riverhead station was laid out a total capacity of nine

receiving sets was planned, six of which are now in daily operation. The amplifiers, detectors, and tuners previously used in the receiving sets of the Radio Corporation were unshielded, and the practise had been, where two sets were in use in the same station, to keep them well separated and operate from separate batteries. To meet the new situation, a new line of apparatus was developed. Each piece of apparatus was in a metal lined box, the metal lining being grounded, and connections between the boxes were made through shielded cable. All tuned inductances consisted of astatic pairs of coils, of compact form, thus reducing chances of magnetic coupling. The radio amplifier was shielded between stages as well as externally. The amplifiers and detector have individual plate and filament filters in the supply lines. A two stage filter was introduced in the circuit between the detector and the audio amplifier in order to prevent radio frequency currents and potentials from getting into the audio circuits where they might cause back coupling or interference between sets. Low resistance telephones were used to minimize electrostatic coupling. These precautions made it possible to operate the several sets in close proximity, and from the same plate and filament batteries, without any interference between sets, and to employ high radio and audio amplification without trouble from back coupling.

Fig. 23—Receiving Station, Riverhead, Long Island

It was usual in receiving the high power European stations to develop a high-frequency potential of about 7 volts at the plate of the last tube in the radio amplifier, with a useful current of about 0.2 milliamperes. By connecting the output of the audio amplifier to a good telephone line, satisfactory tone signals were received and copied in New York City. Beverage arranged a rectifier for the audio frequency currents and operated a telegraph sounder, obtaining very satisfactory signals in this way when static was moderate or light. During the spring of 1921, considerable commercial traffic was received directly in New York in this manner, using the private telegraph wire which connected the Riverhead experimental station with the Broad St. Office of the Radio Corporation. One demonstration which aroused considerable interest consisted in putting Carnarvon's signal on the telegraph line at Riverhead, and automatically repeating it at New York into the New Brunswick control line, so that the operators in the British station heard their own signal coming back on New Brunswick's wave.

When the success of the wave antenna had been demonstrated at Riverhead similar antennas were constructed at Chatham, Mass. and Belmar, N. J. where the Radio Corporation was already operating receiving stations. These new antennas gave satisfactory performance in commercial service until the long wave traffic was finally concentrated in the new Riverhead station which the Radio Corporation constructed during the summer of 1921. Fig. 23 shows the present Riverhead Station. Fig. 24 shows an output transformer, artificial line and potentiometers, Fig. 25 shows shelves with two receiving sets. The building does not provide space for operators, since all signals are transferred to telephone lines and copied directly by operators

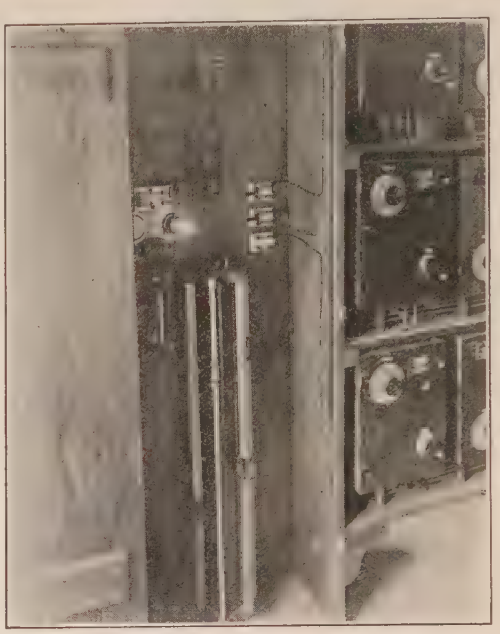

Fig. 24—Antenna Panel, Riverhead Receiving Station

Fig. 25—Shielded Receiving Sets, Riverhead, Long Island

in the New York Office, or recorded automatically on tape.

THEORY[10]

In order to work out a formula by which the directive properties of a wave antenna can be calculated, we shall consider space waves of some specified frequency, since the directive properties of a given antenna depend on the wave length to be received.

Case 1. Signal Direction Parallel to Antenna, Zero Loss Antenna. As the space wave travels along over the antenna, it induces an electromotive force successively in the different portions of the line. We may represent the electromotive force at the end A of the antenna shown in Fig. 26 by

$$e_a = E_0 \sin \omega t \qquad (1)$$

volts per kilometer

FIG. 26—MEASUREMENTS REFERRED TO IN DERIVATION OF EQUATIONS

Since it takes x/v seconds for the space wave traveling with a velocity v to reach the point X, the electromotive force e_x in the wire at the point X will be behind e_a in phase, or

$$e_x = E_0 \sin \omega (t - x/v) \qquad (2)$$

Let us confine our attention for the present to the effects of the electromotive force induced in a small section of the wire $d\,x$ kilometers in length, and situated x kilometers from the end A. Since e_x is expressed in volts per kilometer, the voltage induced in $d\,x$ kilometers of wire will be

$$e_x\,d\,x \text{ or } E_0\,d\,x \sin \omega (t - x/v)$$

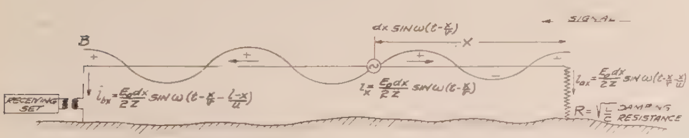

FIG. 27—CURRENTS RESULTING FROM VOLTAGE INDUCED IN SMALL SECTION OF ANTENNA

We may think of this little section of line as an alternator Fig. 27, supplying current to two transmission lines in series, one running to A and the other running to B. A line damped at the far end, so as to prevent reflections, shows an impedance $Z = \sqrt{L/C}$ [11] ohms at the input end, whatever the length of the line. We have here assumed such damping. If each line has an impedance Z ohms the alternator must work through an impedance $2\,Z$ and will produce a current at X,

$$d\,i_x = \frac{e_x\,d\,x}{2\,Z} = \frac{E_0\,d\,x}{2\,Z} \sin \omega (t - x/v) \qquad (3)$$

The alternator at X in forcing the current $d\,i_x$ through the line, gives rise to a train of waves moving toward B and another train of waves moving toward A. The resulting currents at the ends of the line $d\,i_{bx}$ and $d\,i_{ax}$ will be retarded in phase, as compared with $d\,i_x$. If u is the velocity of wave propagation along the wire, it will take $\dfrac{l-x}{u}$ seconds for the forward waves to reach B, and x/u seconds for the backward waves to reach A.

Then
$$d\,i_{bx} = \frac{E_0\,d\,x}{2\,Z} \sin \omega \left(t - x/v - \frac{l-x}{u}\right) \qquad (4)$$

$$d\,i_{ax} = \frac{E_0\,d\,x}{2\,Z} \sin \omega (t - x/v - x/u) \qquad (5)$$

The total current at the end of the line is the sum of

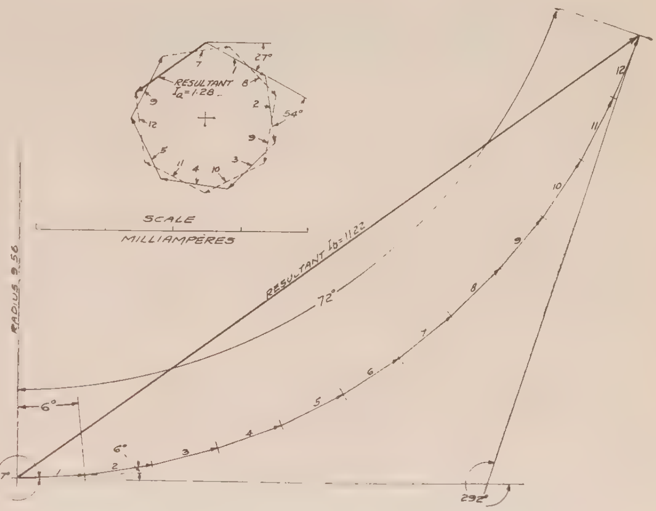

FIG. 28—DETERMINATION OF CURRENTS AT END OF WAVE ANTENNA BY VECTOR DIAGRAMS

the currents produced by each of the sections $d\,x$ long in the line. We may perform the summation by integrating equation (4) or (5) between the limits $x = o$ and $x = l$, or by means of a vector diagram as shown in Fig. 28. The current at the end of the line $d\,i_{bx}$ or $d\,i_{ax}$, resulting from the induced electromotive force in a section $d\,x$ long, situated x kilometers from A, has a maximum cyclic value or vector length $\dfrac{E_0\,d\,x}{2\,Z}$ and a phase angle which varies with x, as shown in expression (4) and (5). Hence the summation will consist in adding a series of vectors, each $\dfrac{E_0\,d\,x}{2\,Z}$ long, and each at its proper phase angle. Taking the phase of e_a for reference, the angle of lag of $d\,i_{bx}$ as shown in (4) is

$$\psi_{bx} = \omega \left(\frac{x}{v} + \frac{l-x}{u} \right)$$

10. The Mathematical work of this paper is due to Kellogg.

11. This expression for Surge Impedance is strictly correct only for zero loss lines, but at radio frequencies it is a very close approximation for ordinary lines.

which may be written

$$\psi_{bx} = \frac{\omega}{u}\left\{ l - x\left(1 - \frac{u}{v}\right)\right\} \tag{6}$$

and from (**5**) the angle of lag of $d\, i_{ax}$ is

$$\psi_{ax} = \omega \left\{ x/v + x/u \right\} = \frac{\omega}{u}\, x \left(1 + \frac{u}{v}\right) \tag{7}$$

A further change in the form of these expressions will make for convenience.

The velocity u is equal to $\frac{1}{\sqrt{L\,C}}$ [12] where L and C are the series inductance and shunt capacity per unit length of line. Then $\omega/u = \omega\sqrt{L\,C}$, which will be recognized as the line wave length constant, for which the symbol β is frequently employed.

If we let n stand for the velocity ratio u/v and substitute β for ω/u we get

$$\psi_{bx} = \beta \left\{ l - x\,(1 - n) \right\} \tag{8}$$

$$\psi_{ax} = \beta\, x\,(1 + n) \tag{9}$$

For the purpose of numerical calculation it is convenient to express β in terms of λ and n as follows:

$$\beta = \omega/u = \frac{2\,\pi\,f}{n\,v} \text{ and since } \lambda = \frac{v}{f},$$

$$\beta = \frac{2\,\pi}{n\,\lambda} \text{ radians per kilometer} \tag{10}$$

These diagrams help us to see how we may write out an expression for the resultant currents. If we divide the line into a large number of very short sections the series of vectors form an arc of a circle instead of a polygon. The length of this arc is the length of one vector $\frac{E_0\, d\,x}{2\,Z}$ multiplied by the number of sections $\frac{l}{d\,x}$ which gives $\frac{E_0\, l}{2\,Z}$. If the vectors all lay on a straight line $\frac{E_0\, l}{2\,Z}$ would be the length of the total current vector. This condition is met at the end B when $u = v$. For any other line velocity, or for the current at the end A, the arc while of the same total length, will have a certain curvature, and the length of the chord subtending the arc, which is the resultant vector, will depend on the curvature. For a given length of arc the curvature is measured by the total angle, or the angle between the first and last vectors, corresponding to $x = 0$ and $x = l$ in (**8**) or (**9**). Thus in the case of the I_b vector addition we put $x = 0$ and $x = l$ in equation (**8**) to obtain the initial and final directions of the arc, which gives

x. (Km.)	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5
ψ b x radians	6.23	6.12	6.02	5.91	5.8	5.7	5.6	5.5	5.38	5.28	5.17	5.06
degrees	357	351	345	339	333	327	321	315	309	303	297	292
ψ a x radians	0.47	1.41	2.35	3.29	4.23	5.16	6.10	7.04	8.0	8.93	9.87	10.80
degrees	27	81	135	189	243	297	352	405	459	513	567	622

Let us illustrate the vector diagram method of summing up the currents by a numerical example. Assume the antenna length l to be 12 kilometers, its wave velocity u equal to 0.8 of that of light, and its impedance Z equal to 500 ohms, and a signal having a wave length of 15 kilometers and an intensity $E_0 = 10$ millivolts per kilometer. In the present case $\beta = \frac{2\,\pi}{n\,\lambda} = \frac{2\,\pi}{(0.8)\,(15)} = 0.522$ radians per kilometer. Take $d\,x$ as 1 kilometer, giving x the values 0.5, 1.5, 2.5, 3.5— to 11.5 kilometers. The corresponding phase angles, figured from expressions (**8**) and (**9**) are

Each vector will have a length $\frac{E_0\, d\,x}{2\,Z} = \frac{0.01 \times 1}{1000} =$ 0.00001 amperes or 10 microamperes. Fig. 28 shows the vector diagrams for the currents at the two ends of the antenna, giving receiver end current $I_b = 112.2$ microamperes and back end current $I_a = 12.8$ microamperes.

$$\psi_{b0} = \beta\, l$$

and

$$\psi_{bl} = \beta\, l\, n$$

The difference or total angle through which the arc turns is

$$\psi_{b0} - \psi_{bl} = \beta\, l\,(1 - n)$$

The radius of curvature r is given by $r = \frac{\text{arc}}{\text{angle}}$ or

$$r = \frac{\frac{E_0\, l}{2\,Z}}{\beta\, l\,(1 - n)} = \frac{E_0\, l}{2\,Z\,\beta\, l\,(1 - n)}$$

The length of the chord which is the vector of the resultant current I_b is given by

chord $= 2\,r \sin 1/2$ (angle) or

$$I_b = 2\,\frac{E_0\, l}{2\,Z\,\beta\, l\,(1 - n)} \sin \frac{1}{2}\,\beta\, l\,(1 - n)$$

Cancelling the $2\,l$ in the numerator and denominator gives

$$I_b = \frac{E_0}{Z\,\beta\,(1 - n)} \sin \frac{1}{2}\,\beta\, l\,(1 - n) \tag{11}$$ [13]

By the same process using equation (**9**) we get

$$I_a = \frac{E_0}{Z\,\beta\,(1 + n)} \sin \frac{1}{2}\,\beta\, l\,(1 + n) \tag{12}$$

12. This expression ignores line losses, but is a very close approximation in all cases with which we shall have to deal. The same is true of the expressions $Z = \sqrt{L/C}$ and $\beta = \omega\sqrt{LC}$

13. A formula which correctly showed the end currents as functions of the antenna length and the velocity ratio, was first worked out during the early Eastport work by Mr. P. S. Carter.

These expressions give I_b = 112 microamperes and I_a = 12.2 microamperes for the problem worked graphically in Fig. 28. The difference between these values and those found from the graphical solution is due to the inaccuracy involved in the graphical method using so few sections.

It will be noticed that if the sign of n is changed in (**11**) we get (**12**). We may consider the sign of the signal velocity v, to be negative when the signal comes from the opposite direction. Since n is defined as u/v, this would give n a negative sign. Therefore, there is only one formula required, and to find the back end current I_a we consider the signal direction to be reversed.

We showed that if $u = v$ the arc is a straight line and $I_a = \frac{E_0 l}{2Z}$. If we set $n = 1$ in (**11**), we get the indeterminate form O/O, and to evaluate the expression we make use of the relation that $\frac{\sin a}{a}$ approaches 1 as a approaches O, where the angle a is expressed in radians. Thus in (**11**)

$$\frac{\sin \frac{1}{2}\beta l(1-n)}{\beta(1-n)}$$

which may be written

$$\frac{\frac{1}{2} l \sin \frac{1}{2}\beta l(1-n)}{\frac{1}{2}\beta l(1-n)}$$

approaches $\frac{1}{2}\, l$ as $\frac{1}{2}\,\beta\, l\,(1-n)$ approaches O, and expression (**11**) takes the value

$$I_b = E_0/Z \times \frac{1}{2}\, l \text{ or } \frac{E_0 l}{2Z}$$

Hence when $u = v$

$$I_b = \frac{E_0 l}{2Z} \qquad (\mathbf{11a})$$

Figure 29[14] shows the receiver end and back end currents calculated by equations (**11a**) and (**12**) for antennas of various lengths, assuming

$u = v = 3 \times 10^5$ kilometers per second
λ = 12 kilometers
E_0 = 0.010 volts per kilometers
Z = 500 ohms

These curves bring out the unidirectional properties of the wave antenna.

14. This figure is practically a reproduction of a curve plotted by Mr. P. S. Carter, based on his calculations previously mentioned.

(To be continued)

ILLUMINATION ITEMS

By the Lighting and Illumination Committee

PLOTTING OF SPECTROPHOTOMETRIC DATA*

During recent years the value of presenting data by a plotted line has been recognized in all branches of industry. However, in all cases where data are so presented, there are none where graphical representation is more useful than in spectrophotemetry. In presenting such data, each author has usually used his own methods in plotting and a lack of uniformity has been the result. The material in this paper has been compiled with a view to presenting some of the details in plotting spectrophotometric curves which will aid in establishing a uniformity of practise.

The Extreme and Useful Limits of Vision

The eye is sensitive to radiations of wave length 0.39 μ to 0.76 μ or 0.77 but these are extreme limits that can be attained only under certain rare conditions. In making up a web to plot the data it is convenient to establish the limits from 0.40μ to 0.70μ. For the sake of simplicity and uniformity it is best practise to make the web extend from these values even if the data points cover only the central part of the web.

Color Boundaries

There does not seem to be any generally accepted definition of the spectrum colors in terms of wave length. While the boundaries used by different writers therefore vary, those used in this laboratory are as follows:

Below 0.400μ, ultra-violet;
0.400μ to 0.424μ, violet;
0.424μ to 0.492μ, blue;
0.492μ to 0.575μ, green;
0.575μ to 0.585μ; yellow;
0.585μ to 0.647μ, orange;
0.647μ to 0.700μ, red;
Above 0.700μ, infra-red.

Since most people think in terms of color rather than wave length, it is of great convenience to have these color boundaries marked in some manner on all spectrophotometric webs.

Choice of Units for Designating Wave Lengths

There are, unfortunately, three units of length used to designate wave lengths of light; the micron, or 10^{-6} meter, designated by μ; the ninth meter, or 10^{-9} meter, designated by $M\ \mu$; and the Angstrom scale or tenth meter (10^{-10} meter). The micron scale, or 10^{-6} meter contains all of the necessary figures of wave length and is sufficiently accurate for all ordinary purposes.

Energy vs. Light

One method of plotting spectrophotometric data is to give the relative energy at each wave length throughout

*Abstract from a paper presented by Frank A. Benford at the 1922 Convention of the Illuminating Engineering Society.

the visible region, paying no attention to the visibility of radiation except in the matter of limits. The curve is, therefore, purely an energy curve and a great deal of interpretation is needed to get it into terms of light. This curve can be reduced to a curve of light by multiplying the various energy value by the visibility at the different wave lengths. The area under the reduced curve then represents light and each portion of the spectrum is given to a proper scale. The shortcoming of this curve is that it has lost much of its graphic value, due to the strong characteristic form of the visibility curve covering and concealing the variations that were easily seen in the original curve.

A little more than a year ago the writer had occasion to plot the transmission data of twenty-one dyes and filters used in the motion picture industry so as to show: (a) transmission of each wave length (b) average transmission for entire visible spectrum (c) relative luminosity of the different parts of the transmitted spectrum.

The web was constructed by plotting a visibility curve to a large scale and the ordinates measured at close intervals. Beginning at 0.40μ the ordinates were added together one at a time and the summation curve so obtained was plotted which represented the summation of the light from a source of uniform intensity from end to end of the spectrum.

The areas under the visibility curve from 0.40μ up to various wave lengths were read from this summation curve and used to get the spacing of the ordinates for

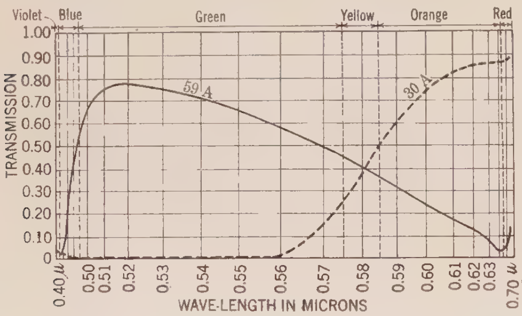

Fig. 1—Spectrophotometric Test. Transmission of Wratten Filters 59A and 30A

the curve of transmissivity. As a result, the space between, 0.55μ and 0.56μ on the web is proportional to the light between these limits from a source of uniform intensity of radiation.

A curve of transmissivity, or reflectivity, or radiation plotted on this web fulfills conditions (*a*), (*b*), and (*c*) above and at the same time all parts of the curve are readable and retain an individuality of form midway between the energy curve and the reduced luminosity curve. The area under such a curve divided by the whole area of the web gives the net transmissivity.

Point of Equality

In studying the light from any given source we consider the quantity an quality as two district characteristics and in nearly all cases two distinct tests, photometric and spectrophotometric, are made. The spectrophotometric data need not then be plotted to an absolute scale as the curve is supposed to show only relative intensities throughout the spectrum. Under this condition any scale of ordinates may be used, but there has grown up a certain convention in the use of the vertical scale that makes for ease in comparing the data of various curves.

A number of years ago it was customary to make all emission curves pass through unity at 0.59μ. Later knowledge and the fact that the color of the common illuminants changed with the adoption of hotter light sources has fixed this point at 0.55μ.

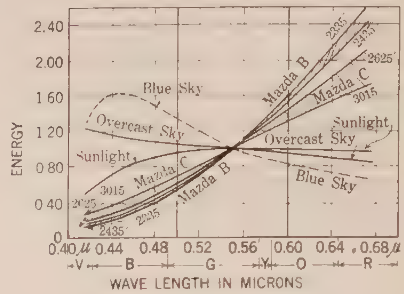

Fig. 2—Spectrophotometric Test

Blue Sky, Overcast Sky and Sunlight from Proc. I. E. S., 1910, pages 193, 194 and 195. Mazda B at 2334 degrees—2435 degrees absolute; computed. Mazda C at 2625 degrees, 3015 degrees absolute;—computed.

Every spectrophotometric curve should have shown along with it the actual points. Often when dealing with continuous spectra a smooth curve can be drawn through all points. However, in every case the points should be given since the with points given, the reader can accept, reject, or alter the curve to suit his judgment.

The great use of the common point is in the assembling of several curves on the same sheet so that they may be compared. In this way various illuminants may be readily compared for quality. Fig. 2 shows curves plotted for comparisons.

Prism Spectrum and Grating Spectrum

In testing with a continuous spectrum the operator has considerable freedom in the choice of test points, and usually they will be selected at equal wave length spacings regardless of whether the spectrum is formed by a prism or a grating. But when a discontinuous spectrum is being measured for light, no section of the spectrum should be omitted, otherwise an important line or band might be missed; also, no section of the spectrum should be included in the readings on two adjacent test sections.

Absolute and Comparative Values

The curves of reflectivity and transmission should always be plotted to an absolute scale. There is no justification for not having these curves to exact scale, for if they are displaced upward or downward by a constant factor, they cease to truly represent the facts.

In the use of an absolute scale, a practise that is a common cause of annoyance is the "suppressed zero" or web beginning with some figure other than zero on the vertical scale. In such cases, the individual points must be read to get a correct idea of the data and the curve is not much more useful than a mere tabulation of the data. However, where the data is restricted to a small section of the web and the work has been done with such precision that the smaller details of the curve has some meaning other than experimental errors, the suppressed zero is useful.

OVERCOMING DAYTIME REFLECTIONS IN SHOW WINDOWS*

Buildings and objects on the street having a greater relative brightness than the objects in a show window are reflected in the plate glass hindering the visibility of the display in the window. Such reflections are a source of considerable annoyance in show windows. The apparent transparency of the glass is reduced to such an extent that it is impossible to discern the details of a display within the window; the result is a corresponding decrease in the effective value of the display.

Overcoming Daytime Reflections in Show Windows

Fig. 1—View of figure on window by natural light alone with the camera so located as to show the reflections of the sky line of the street opposite the store. It will be noticed that the upper part of the figure is practically invisible.

Fig. 2—Conditions are identical with Fig. 1 except that the special ighting is turned on.

When one realizes that store managers whose windows are located on an important, busy street estimate the advertising value of their windows at from $50,000 to $150,000 a year, the undesirability of daytime reflections can be appreciated.

By decreasing the difference in brightness between the reflected object and the objects of the display, the reflections can be overcome to a great extent. With this fact in mind, an investigation was conducted to determine the possibility of overcoming these reflections by the use of a high level of illumination within the windows.

It can be readily seen that to reduce the difference in brightness between the objects on display and the objects reflected in the window glass will require a high level of illumination in the show window. Objects which are reflected in the windows are illuminated by sunlight from 1000 to 5000 foot-candles, while the objects of a display will be illuminated to much lower values; turning on the ordinary window lighting installation has practically no effect. To be effective then the brightness of the objects within the window must approach the brightness of the images on the surface of the glass; this will require from 1000 to 2000 foot-candles.

The window of the Lindner Company, Cleveland, Ohio, where reflections had been particularly troublesome on account of the location, was used for the investigation. Six spotlights or flood lights of approximately 25,000 beam candle-power each were installed in such a way as to provide a maximum flexibility of light direction and control facilitating the use of the light for various displays. By means of these spotlights, it was possible to concentrate the light upon the important objects in the window thereby increasing the relative brightness of the objects within the window as compared to the reflections of those without. By lighting the individual objects to a high level of illumination the desired results are accomplished without floodlighting the entire window which would involve a corresponding increase in wattage consumption.

Abstract from a paper by Ward Harrison and H. T. Spaulding presented before the 1922 Convention of the Illuminating Engineering Society.

RADIO RECEPTION

Publications of Bureau of Standards

Announcement has previously been made of the publication of Bureau of Standards Circulars 120 and 121, entitled "Construction and Operation of a Simple Homemade Radio Receiving Outfit" and "Construction of a Two-Circuit Radio Receiving Equipment with Crystal Detector," respectively. These two circulars describe crystal detector receiving sets and either of them can be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C., at 5 cents a copy.

To meet what appears to be a very considerable demand, the Bureau of Standards has prepared Circular No. 133, entitled "Description and Operation of an Electron-Tube Detector Unit for Simple Radio Receiving Outfits." This circular describes in detail the construction and operation of a simple electron-tube detector unit which will give a much more sensitive set than one employing a crystal detector and may, therefore, be expected to give more satisfactory results. Much of the apparatus belonging to the sets described in Circulars 120 and 121 can be used for the new arrangement, and the cost of the electron-tube detector unit alone, including tubes, is estimated to be not greater than $8 to $14. In addition, however, batteries will have to be purchased which add about $20 to the cost of the outfit.

Circular 133 can be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C., at ten cents per copy.

Frequency Conversion by Third Class Conductor
and
Mechanism of the Arcing Ground and other Cumulative Surges

BY CHARLES P. STEINMETZ

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Review of the Subject.—*In high-voltage power circuits, such as transmission lines and the high-voltage coils of large power transformers, not infrequently disturbances are observed of a frequency differing from, and usually very much higher than that of the power supply, and differing from the typical transient of energy readjustment, in that they do not gradually die out, but increase in intensity until either destruction occurs, or they finally limit themselves. Such cumulative oscillations or arcing grounds derive their energy from the machine power of the system, and so constitute a frequency transformation, of which the mechanism has been little understood.*

Physically they may be derived from the typical condenser discharge by the conception of a **negative resistance,** *in combination with a* **source of power,** *which supplies the energy given out by the negative resistance.*

Attention is drawn to a class of conductors—to which arcs and gas discharges belong—the so-called "third-class conductors," in which the voltage decreases with increase of current, and it is shown that these conductors can be considered as a combination of a negative resistance with a source of power, and as such are capable of transforming the low machine frequency into a high oscillation frequency of alternating currents, and their presence in an electric system thereby may produce cumulative oscillations.

The general equations are then derived of a system comprising a third-class conductor shunted by an inductive circuit containing capacity, and supplied with voltage over an inductive circuit from an alternating low-frequency source, and it is shown that in such a system currents and voltages of two distinct frequencies may continuously exist, of which the one is the machine frequency, the other a high oscillation frequency. It is further shown that the voltage of the latter is limited only by the resistance of the oscillating circuit, and in low-resistance circuits may build up to very high values. Furthermore, the high oscillation frequency is essentially limited to the circuit shunting the third-class conductor and but little of it enters the supply circuit, while the supply frequency enters the shunt circuit to a limited extent only, and both frequencies are superimposed in the third-class conductor as the frequency converter.

CONTENTS

A. Physical Explanation

I. The Third Class Conductor

In a first class or metallic conductor, the voltage increases slightly more than proportional to the current, due to a positive temperature coefficient of resistance.

In a second class or electrolytic conductor, the voltage increases slightly less than proportional to the current, due to a slightly negative temperature coefficient of resistance.

As third class conductor may be defined a conductor in which, at least within a certain range of current, the voltage *decreases* with *increase* of current. Third class conductors comprise different types, such as

(a) Electronic or vacuum, gas or Geissler tube (spark) and vapor or arc conduction. In these the decrease of voltage with increase of current is due to the change of the conducting path by the current.

(b) Most of the so-called insulators probably are third class conductors. In these the decrease of voltage with increase of current is a temperature effect. That is, the negative temperature coefficient of resistance is so large that—at least in a certain range—the increase of the conductor temperature with increasing current decreases the resistance more than the current increases.

In Fig. 1, *I* gives the volt-ampere characteristic of a metallic conductor, *II* of an electrolytic conductor, and *III* of an arc as third class conductor. Fig. 2, gives the volt-ampere characteristic of a pyroelectric

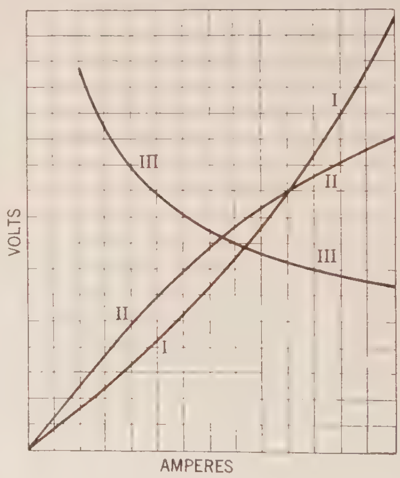

FIG. 1—VOLT-AMPERE CHARACTERISTICS OF DIFFERENT CONDUCTOR TYPES

1. First class or metallic conductor
2. Second class or electrolytic conductor
3. Arc as third class conductor

conductor, a Nernst lamp glower, which in the range above 0.02×10^{-3} ampere is a third class conductor

(plotted for convenience with the fourth root of current and voltage as coordinates).

Such a volt-ampere characteristic of a third class conductor can be considered as a combination of a constant e. m. f. E_1 and an effective negative resistance r_1:

$$e = E_1 - r_1 i$$

The effective negative resistance r_1 decreases with increase of current, as $r_1 i$ must always remain smaller than E_1.

II. Time Lag

If the current in the third class conductor varies periodically, between i_1 and i_2, the voltage also will vary periodically, between e_1 and e_2, and if the variation is slow enough so that at every value of current stationary condition is reached, the variation of voltage is inverse to that of current. That is, if i_1 is the minimum value of current, the corresponding value of voltage e_1 is the maximum value, and inversely. If however, the variation is sufficiently rapid, a lag of the voltage occurs

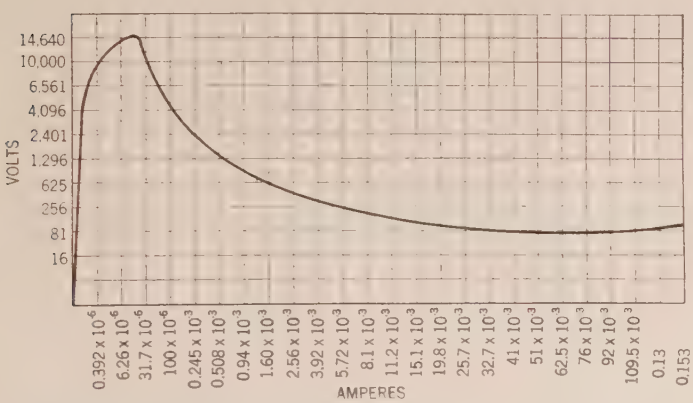

Fig. 2—Volt-Ampere Characteristics of Nernst Lamp Glower
As Third Class Conductor

behind the current, that is, the maximum value of voltage is not reached at the minimum value of current, but a little later, and so the minimum value of the voltage is reached a little later than the maximum value of current, and correspondingly, the amplitude of the variation is reduced, the more so, the more rapid the pulsation.

This time lag of the third class conductor, and the reduction of amplitude of variation resulting from it, depends on the nature of the conductor. It is extremely small in ionic conduction, but may be very considerable where the variation of the effective resistance of the third class conductor is a temperature effect.

As first approximation, the periodic variations of current and voltage in a third class conductor thus may be expressed by:

$$i = I_0 - I \sin 2 \pi f t$$
$$e = E_0 + E \sin (2 \pi f t - \varphi)$$

where the lag angle φ increases with increasing frequency f of the pulsation. It is negligible for very low frequency, and becomes 90 deg., and the amplitude of the resistance variation therefore negligible, for very high frequency.

In ionic conduction, φ is still small at ratio frequencies; in the Nernst lamp glower (temperature effect) φ is already practically 90 deg. at 60 cycles.

The volt-ampere characteristic of the third class conductor under rapidly varying current (its "transient characteristic") thus differs more or less from its "permanent" characteristic as shown in Figs. 1 and 2.

III. The Condenser Discharge

If a condenser of capacity C discharges through an inductance L and (constant) ohmic resistance r, and the latter is below the critical value, the discharge current is oscillatory, that is, consists of successively alternating half waves of constant frequency and uniformly decreasing amplitude. The decrease of the current, or the "attenuation" is given by the exponential factor:

$$A = \epsilon^{-\frac{r}{2L} t}$$

If then the discharge circuit of the condenser contains, besides the ohmic resistance r, a third class conductor of the effective negative resistance r_1, the attenuation of the condenser discharge is:

$$A = \epsilon^{-\frac{r - r_1}{2L} t}$$

Thus, if the effective negative resistance r_1 is greater than the ohmic resistance r, the exponent

$$-\frac{r - r_1}{2L} t$$

is positive, and A increases with the time t, thus is not an attenuation but an accumulation. The amplitudes of successive half waves of the condenser discharge current then progressively increase, that is, we get a cumulative surge.

As seen in I, the effective resistance r_0 of the third class conductor decreases with increase of current. In such a cumulative surge produced by the presence of a third class conductor in the inductive condenser discharge circuit, the successive half waves of current will progressively increase, until by the increase of current the effective negative resistance r_1 has decreased to equality with the ohmic resistance r, and the exponent of the exponential term A has become zero, $A = 1$, and the successive half waves of the condenser discharge current become equal, that is, an alternating current results.

Thus the final result of a condenser discharge through a third class conductor of sufficiently high effective negative resistance is an alternating current of a frequency determined by the circuit constants.

IV. Energy Relations

A current i through the effective negative resistance $- r_1$ consumes a voltage $- r_1 i$ which is in phase with the current, thus represents electric power generation.

Hence an effective negative resistance can exist independently only in the presence of some other source of energy, supplying the power (mechanical drive for instance). Thus an electric generator may be considered as an effective negative resistance. The most typical negative resistance is the induction machine driven above synchronism, since (below saturation) it generates a voltage proportional to the current, thus is a constant negative resistance.

As seen in *I*, a third class conductor may be considered as the combination of a counter e. m. f. E_1, and an effective negative resistance $-r_1$: $e = E_1 - r_1 i$. As $r_1 i$ must always remain smaller than E_1, therefore the power generated by the effective negative resistance: $-r_1 i^2$ always is less than the power consumed by the counter e. m. f. E_1: $E_1 i$ and the counter e. m. f. E_1 thus abstracts from the electric circuit the power which is returned by the effective negative resistance r_1.

In the condenser discharge through a third class conductor, the current wave builds up cumulatively by the effective negative resistance r_1, but the condenser voltage is lowered discontinuously by the counter e. m. f. E_1, at every reversal of current, and with it the current wave is lowered, and as E_1 is greater than $r_1 i$, the discharge oscillation gradually dies out, (though by a different law than in the standard condenser discharge equation,) as discussed in a previous paper.[1]

If however the counter e. m. f. E_1 of the third class conductor is supplied by some outside source of electric power, and therefore does not abstract energy from the condenser discharge, then the cumulative effect of the negative resistance of the third class conductor r_1 on the condenser discharge current i would continue until limited by the decrease of r_1 with increasing i, and an alternation results.

Now the importance of this phenomenon is, that the character of the supply voltage giving the counter e. m. f. E_1 has no necessary relation to the frequency of the condenser discharge; the latter is determined by the values of the capacity and inductance, and may be a high or very high frequency, while E_1 may be of machine frequency, 25 or 60 cycles, or even continuous voltage. The power supplied by the effective negative resistance to the high-frequency condenser discharge is derived from the counter e. m. f. E_1 and the latter is fed from the low-frequency machine power. We therefore have here a frequency transformation giving a steady power supply to the high-frequency oscillation, so that the latter are not any more limited energy transients, but unlimited power permanents, of corresponding destructiveness. As such they have been frequently observed in electric power systems, as arcing grounds in transmission lines, and as high-frequency cumulative surges in the high-voltage coils of large power transformers.

As the exact mechanism of this frequency transformation from the low machine power frequency to the high frequency of the cumulative surge is not generally familiar, the following may be of interest, though a similar problem has been studied in a different manner in radio engineering in the theory of the vacuum tube as oscillator.

V. Frequency

Suppose a condenser of capacity C discharges through an inductance L, an ohmic resistance r and a third class conductor N, and upon this third class conductor, a constant alternating voltage e_0 is impressed through a supply circuit of resistance r_0 and inductance L_1, as shown diagrammatically in Fig. 3. We can consider the arrangement as a divided circuit consisting of a third class conductor N in shunt to the circuit C, L, r, and energized over the circuit L_0, r_0 by voltage e_0.

We can assume that r is sufficiently small to make the condenser discharge oscillatory, and that the frequency f of this oscillation is high compared with the frequency f_0 of the supply voltage e_0.

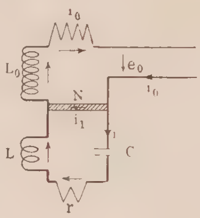

Fig. 3—Circuit Diagram of Frequency Transformation by Third Class Conductor

N. Third class conductor
C = Capacity, L = inductance, r = resistance of shunt circuit
L_0 = Inductance, r_0 = resistance of supply circuit
e_0 = low-frequency supply voltage

Denoting then the currents in the two branch circuits by i and i_1, the voltage by e_1, the differential equations can be written as those of a circuit containing resistance, inductance and capacity.

As seen therefore, if the effective negative resistance of the third class conductor is sufficiently high, the oscillatory starting transient of the condenser C does not die out, but cumulatively increases in amplitude, until limited by the decreasing negative resistance, and so reaches an alternating sine wave as final value, i, i_1 and e_1 then must consist of sine waves.

The differential equations are therefore integrated by representing i, i_1 and e_1 by summation of sine waves.

$$\Sigma B \sin (q t - \beta)$$

substituting these into the differential equations, and from the identities thus produced, calculate the constants B, β etc.

One of the terms must be of the supply frequency $q = 2 \pi f_0$, and the amplitude and the phase angle of its currents and voltages are given by the terminal condition, that the supply voltage is e_0.

This term merely gives the permanent low-frequency alternating current and voltage distribution in the divided circuit Fig. 3.

1. Condenser Discharge Through a Gas Circuit A. I. E. E., Feb. 1922.

For all other terms in the solution of the differential equation, the impressed e. m. f. equals zero. This condition gives an equation, which determines the frequency $q = 2\pi f$, of the term.

It follows therefore, that besides the low-frequency term of the supply frequency f_0, only one second term can exist, in the equations of current and voltage, of an oscillation frequency f of the condenser discharge circuit.

The frequency of local oscillation f, which from the viewpoint of frequency transformation may be called the "secondary frequency" depends on the constants of the circuit, and therefore has no numerical relation to the supply or "primary" frequency, is not a multiple or a higher harmonic of it, as in most other frequency transformations.

VI. Amplitude

If an alternating supply voltage is impressed upon a third class conductor contained in an inductive condenser discharge circuit, the transient condenser oscillation may build up to a permanent high-frequency alternation. Current and voltage then contain two terms. The first or low-frequency one is that due to the impressed e. m. f. In the second the frequency is determined by the circuit constants, but the amplitude thus far left indeterminate. The amplitude of the high-frequency current and voltage thus increases, until finally limited by the decreasing effective negative resistance of the third class conductor, and by the supply voltage.

As the effective negative resistance of the third class conductor must be greater than the ohmic resistance of the circuit, to give a cumulative oscillation, and as this effective negative resistance decreases with increase of current, the limit, to which the high-frequency alternating current can build up, is that value, at which the effective negative resistance of the third class conductor had decreased to equality with the ohmic resistance of the circuit, as discussed in III.

As the only source of power is the low-frequency supply by the impressed voltage e_0, this must always be positive. That is, in the voltage e_1 and the current i_1 of the third class conductor, the high-frequency term —which absorbs power—if of opposite sign of the low-frequency term—which supplies the power—must always be less than the low-frequency term, to maintain positive power. This means, the maximum value of the high-frequency term must be less than the instantaneous value of the low-frequency term at the moment when the maximum value of the high-frequency term occurs. Therefore the amplitude of the high-frequency term is not constant, but periodically rises and falls, with the frequency of the low-frequency term and the latter thus is the envelope of the high-frequency term, as illustrated in Fig. 4.

The difference between this type of condenser discharge, and the standard form is that in the latter the envelope of the periodic discharge current is exponential, and the current thus gradually dies out, as transient, while in the present case, with power supply through a third class conductor, the envelope of the condenser discharge current is a low-frequency sine wave, and the discharge current thus periodically rises and falls, but persists as permanent.

Such a periodically rising and falling alternating wave can be considered as the superposition of two waves, differing in frequency from each other by the frequency of the beats, that is, in the present case, twice the frequency of the supply voltage; hence of the frequency $f - f_0$ and $f + f_0$. However, as at very low currents the third class conductor usually ceases to represent an effective negative resistance, the periodic high-frequency oscillation usually dies out in a short range at the reversal of the low-frequency wave, and then starts again at the rise of the latter, as indicated diagrammatically in Fig. 4, and the phases of the groups of the high-frequency waves in the successive low-frequency half waves therefore are independent of each other. The resolution of the high-frequency waves into two components of different frequency therefore has no physical significance.

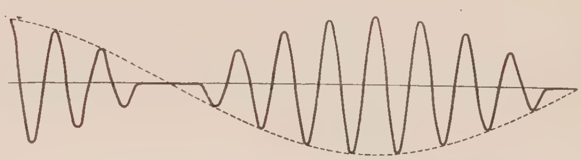

Fig. 4—High-Frequency Secondary and Low-Frequency Primary Wave of Frequency Transformation by Third Class Conductor

As the maximum value of the high-frequency wave is limited to the instantaneous value of the low-frequency wave, the mean square of the maximum value of the high-frequency wave is limited to the mean square of the instantaneous value, and therefore to half the square of the maximum value of the low-frequency wave. This means, that the power of the high-frequency alternation is limited to half the power of the low-frequency wave; in other words, under the conditions herein considered, the efficiency of the frequency transformation cannot exceed 50 per cent.

If the secondary frequency f is much higher than the primary frequency, very little low-frequency enters the supply circuit, since it is kept out by the high capacity reactance, at the low-frequency of the condenser C, and very little high-frequency current enters the supply circuit, since it is kept out by the high inductive reactance, at the high frequency, of L_0. Thus the capacity shunt is essentially a high-frequency circuit, the supply a low-frequency circuit, and both frequencies concur in the third class conductor, in which the transformation takes place.

B. Mathematical Calculation

I. General Equation

Let a third class conductor be shunted by a circuit of capacity C, inductance L, and ohmic resistance r and supplied by a constant alternating e. m. f. of machine frequency, over a resistance r_0 and inductance L_0.

We may assume that r is below the critical value, so that the current in C, L, r is oscillatory, and that the frequency of oscillation of this circuit is high compared with the machine frequency, and that L_0 is large compared with L.

Let the alternating supply e. m. f. be a sine wave:

$$e_0 = E_0 \sin (q_0 t - \alpha) \quad (1)$$

where:

$q_0 = 2 \pi f_0 t$,

and,

f_0 = frequency of power supply.

Let:

e_1 = voltage at the terminals of the third class conductor

i_1 = current in the third class conductor

i = current in the circuit C, L, r shunting the third class conductor

e' = voltage at the terminals of the condenser C.

e_0, e_1, i_1, i and e' being counted in the direction as indicated by the arrows in Fig. 3.

It is then, at the condenser C:

$$i = C \frac{d e'}{d t} \quad (2)$$

It is, in the closed circuit between the third class conductor and the capacity inductance shunt:

$$e_1 = e' + r i + L \frac{d i}{d t} \quad (3)$$

Hence, differentiating (3) and substituting (2) therein, gives:

$$\frac{d e_1}{d t} = i/C + r \frac{d i}{d t} + L \frac{d i^2}{d t^2} \quad (4)$$

It is, in the supply circuit:

$$e_0 = e_1 + r_0 (i_1 + i) + L_0 \frac{d (i_1 + i)}{d t} \quad (5)$$

and the voltage across the condenser terminal is, by (3):

$$e' = e_1 - r i - L \frac{d i}{d t}$$

Assuming that the circuits have been closed sufficiently long to reach stationary conditions, that is, that the starting transient has passed and any cumulative oscillation which may occur has built up to its final value.

e_1, i_1 and i then must be periodic functions, and as such may be represented by a sume of sine waves:

$$\left.\begin{aligned} e_1 &= \Sigma E_1 \sin (q t - \beta) \\ i_1 &= \Sigma I_1 \sin (q t - \gamma) \\ i &= \Sigma I \sin (q t - \omega) \end{aligned}\right\} \quad (7)$$

Substituting (7) into (3) then must give an identity, that is, the coefficient of $\cos q t$ and $\sin q t$ must individually disappear. This gives:

$$E_1 \cos \beta = I (r \cos \omega - R \sin \omega)$$

$$E_1 \sin \beta = I (r \sin \omega + R \cos \omega)$$

where

$$R = \frac{1}{q C} - q L \quad (8)$$

Herefrom follows:

$$E_1 = z I \quad (9)$$

and

$$\tan \omega = \frac{r \sin \beta - R \cos \beta}{r \cos \beta + R \sin \beta} \quad (10)$$

where:

$$z = \sqrt{R^2 + r^2} \quad (11)$$

Substituting (1) and (7) into (5) then gives:

$$E_0 \sin (q_0 t - \alpha) = \Sigma E_1 \sin (q t - \beta) + \Sigma z_0 \{ I_1 \cos (q t - \gamma - \zeta) + I \cos (q t - \omega - \zeta) \} \quad (12)$$

where:

$$z_0 = \sqrt{q^2 L_0^2 + r_0^2} \quad (13)$$

$$\tan \zeta = \frac{r_0}{q L_0} \quad (14)$$

II. Low Frequency Terms

(12) also must be an identity. That is, the coefficients of $\cos q t$ and $\sin q t$ must individually vanish. This gives, for: $q = q_0$; denoting the terms by the index O:

$$\left.\begin{aligned} E_0 \sin \alpha &= E_1 \sin \beta_0 - z_0 \{ I_1 \cos (\gamma_0 + \zeta_0) + I \cos (\omega_0 + \zeta_0) \} \\ E_0 \cos \alpha &= E_1 \cos \beta_0 + z_0 \{ I_1 \sin (\gamma_0 + \zeta_0) + I \cos (\omega_0 + \zeta_0) \} \end{aligned}\right\} \quad (15)$$

Let:

$$r_1 = E_1 / I_1 \quad (16)$$

= effective resistance of the third class conductor.

Substituting (**16**) and (**9**) into (**15**), gives two equations in I and α, which resolved give:

$$I = \frac{E_0}{\sqrt{\left[z_0 \left\{\frac{z_0}{r_1}\cos(\gamma_0+\zeta_0)+\cos(\omega_0+\zeta_0)\right\} - z_0\sin\beta_0\right]^2 + \left[z_0\left\{\frac{z_0}{r_1}\sin(\gamma_0+\zeta_0)+\sin(\omega_0+\zeta_0)\right\}+z_0\cos\beta_0\right]^2}} \quad (17)$$

$$\tan\alpha = \frac{z_0\sin\beta_0 - z_0\left\{\frac{z_0}{r_1}\cos(\gamma_0+\zeta_0)+\cos(\omega_0+\zeta_0)\right\}}{z_0\cos\beta_0 + z_0\left\{\frac{z_0}{r_1}\sin(\gamma_0+\zeta_0)+\cos(\omega_0+\zeta_0)\right\}} \quad (18)$$

These expressions can be very much simplified by neglecting terms of secondary order, and choosing the phase of the current in the third class conductor as base line, that is, $\gamma_0 = 0$.

For the low frequency $q = q_0$, the time lag of the third class conductor can be neglected, giving $\beta_0 = \gamma_0 = 0$. By (**10**), this gives

$$\tan\omega_0 = - R_0/r \quad (19)$$

Neglecting the resistance r_0 against the reactance of the supply circuit $x_0 = q_0 L_0$, gives by (**14**) $\zeta_0 = 0$, and by (**13**):

$$z_0 = q_0 L_0 = x_0 \quad (20)$$

For the low-frequency $q = q_0$, $q_0 L$ is negligible against $\frac{1}{q_0 C}$, and, denoting the latter, the capacity reactance, by

$$k = \frac{1}{q_0 C} \quad (21)$$

it is by (**8**), (**11**), (**9**) and (**19**):

$$\left.\begin{aligned} R_0 &= k \\ Z_0 &= k \\ E_1{}^0 &= k\, I \\ \tan\omega_0 &= - k\, r \end{aligned}\right\} \quad (22)$$

Thus approximately:

$$\omega_0 = - 90 \text{ deg.}$$

and we now get from (**17**) and (**18**):

$$I^0 = \frac{E_0}{k\sqrt{\left(\frac{x_0}{r_1}\right)^2 + \left(1 - \frac{x_0}{k}\right)^2}} = \frac{E_0}{k\sqrt{\left(\frac{x_0}{r_1}\right)^2 + 1}} \quad (23)$$

$$\tan\alpha = -\frac{x_0}{r_1}\left(1 + \frac{x_0}{k}\right) = -\frac{x_0}{r_1} \quad (24)$$

and herefrom the approximate values of E^0, $I_1{}^0$, etc.

III. High-Frequency Terms

In the identity (**12**), it is for:

$$q \neq q_0$$

$$\left.\begin{aligned} 0 &= E_1\sin\beta - z_0\{I_1\cos(\gamma+\zeta) + I\cos(\omega+\zeta)\} \\ 0 &= E_1\cos\beta + z_0\{I_1\sin(\gamma+\zeta) + I\sin(\omega+\zeta)\} \end{aligned}\right\} \quad (25)$$

Substituting (**9**) into (**25**) and rearranging; gives:

$$\left.\begin{aligned} z_0 I_1\cos(\gamma+\zeta) &= I\{z\sin\beta - z_0\cos(\omega+\zeta)\} \\ z_0 I_1\sin(\gamma+\zeta) &= - I\{z\cos\beta + z_0\sin(\omega+\zeta)\} \end{aligned}\right\} \quad (26)$$

Thus

$$\tan(\gamma+\zeta) = \frac{z_0\sin(\omega+\zeta) + z\cos\beta}{z_0\cos(\omega+\zeta) - z\sin\beta} \quad (27)$$

If L_0 is large compared with L, then z is small compared with z_0, and can be neglected against it, and it thus is:

$$\tan(\gamma+\zeta) = \tan(\omega+\zeta) \quad (28)$$

$$\gamma = \omega \quad (29)$$

Substituting (**29**) into (**10**) and rearranging, gives:

$$\begin{aligned} R/r &= \tan(\beta - \gamma) \quad (30) \\ &= \tan\delta \end{aligned}$$

where

$$\delta = \beta - \gamma \quad (31)$$

is the phase difference between current and voltage in the third class conductor, or the time lag angle of the third class conductor.

Substituting (**8**) into (**30**), and resolving, gives:

$$q = -\frac{r}{2L}\tan\delta + \sqrt{\frac{1}{L\,C} + \frac{r^2}{4L^2}\tan^2\delta} \quad (32)$$

[If the angle of time lag of the third class conductor vanishes: $\delta = \beta - \gamma = 0$, that is, current and voltage are in phase with each other, then

$$q = \frac{1}{\sqrt{L\,C}}$$

the same is the case, if $r = 0$, that is, the ohmic resistance of the condenser inductance shunt is negligible.]

As seen, only two terms can exist in the equation (**6**) the one with q_0, of the machine frequency, due to the impressed voltage e_0, and the one with q, (**32**), the frequency of oscillation of the inductive condenser circuit.

From (**30**), (**11**) and (**9**) follows:

$$R = r\tan\delta$$

$$z = \frac{r}{\cos\delta} \quad (33)$$

$$I = \frac{E_1\cos\delta}{r}$$

and by substituting into (**26**), and neglecting r against z_0, gives:

$$I_1 = - I = -\frac{E_1\cos\delta}{r} \quad (34)$$

IV. Amplitude

Combining the low and high-frequency terms then gives the total expressions of current and voltage:

$$\left.\begin{aligned}
e_0 &= E_0 \sin (q_0 t + \alpha_0)\\
\tan \alpha_0 &= + \frac{x_0}{r_1}\\
e_1 &= \frac{E_0}{\sqrt{1 + \left(\frac{x_0}{r_1}\right)^2}} \sin q_0 t + E_1 \sin (q t - \delta)\\
q &= - \frac{r}{2L} \tan \delta + \sqrt{\frac{1}{L\,C} + \frac{r^2}{4L^2} \tan^2 \delta}\\
i_1 &= \frac{E_0}{\sqrt{r_1^2 + x_0^2}} \sin q_0 t - \frac{E_1 \cos \delta}{r} \sin q t\\
i &= \frac{E_0}{k\sqrt{1 + \left(\frac{x_0}{r_1}\right)^2}} \cos q_0 t + \frac{E_1 \cos \delta}{r} \sin q t\\
i_0 &= i_1 + i\\
&= \frac{E_0}{\sqrt{r_1^2 + x_0^2}} \{\sin q_0 t + r_1/k \cos q_0 t\}
\end{aligned}\right\} \quad (35)$$

where:

$$\left.\begin{aligned}
q_0 &= 2\pi f_0\\
x_0 &= q_0 L_0\\
k &= \frac{1}{q_0 C}
\end{aligned}\right\} \quad (36)$$

r_1 = resistance of third class conductor.

Substituting into equation (**6**), gives the terminal voltage e' of the condenser C.

$$e' = \frac{E_0}{\sqrt{1 + \frac{x_0^2}{r_1^2}}} \sin q_0 t = E_1 \left(\sin \delta + \frac{q L}{r} \cos \delta \right) \cos q t \quad (37)$$

As seen, the high-frequency term of e' indefinitely increases with decreasing r. That is, the cumulative oscillation builds up to the resonance voltage of L and C, or until limited by the ohmic resistance.

Thus, where r is small, as in the high-voltage coils of power transformers, very high voltages may be produced.

As discussed in *A III* the second term in i_1 and e_1 must always be smaller than the first term. That is, it must be, in i_1:

$$\frac{E_1 \cos \delta}{r} < \frac{E_0}{\sqrt{r_1^2 + x_0^2}}$$

Thus we may substitute:

$$\frac{E_1 \cos \delta}{r} = p \frac{E_0}{\sqrt{r_1^2 + x_0^2}} \quad (38)$$

where:

$$p < 1 \quad (39)$$

Equations (**35**) thus become:

$$\left.\begin{aligned}
i_1 &= \frac{E_0}{\sqrt{r_1^2 + x_0^2}} \sin q_0 t \{1 - p \sin q t\}\\
&\text{and:}\\
e_1 &= \frac{E_0}{\sqrt{1 + \frac{x_0^2}{r_1^2}}} \sin q_0 t \left\{ 1 + p \frac{r}{r_1 \cos \delta} \sin (q t - \delta) \right\}
\end{aligned}\right\} \quad (40)$$

As the second term in e_1 must be less than the first, it must be:

$$\frac{p\,r}{r_1 \cos \delta} \leqq 1$$

or:

$$r = \leqq \frac{r_0 \cos \delta}{p}$$

or:

$$r_1 \cos \delta \geqq p\,r$$

Herefrom follows:

(1) With a given resistance r of the oscillating circuit, the oscillation increases, that is, current and voltage build up, until they reach the values, at which the transient effective negative resistance of the third class conductor, $r_1 \cos \delta$, has dropped down to equality with the resistance r, or rather slightly lower.

(2) When in the inductive condenser shunt to a third class conductor, the ohmic resistance r is increased, the cumulative high-frequency oscillation still occurs—though of an amplitude decreasing with increase of the resistance r—until the ohmic resistance becomes equal to the transient negative resistance of the third class conductor, $r_1 \cos \delta$, or rather slightly larger. Then the oscillation stops.

(3) The amplitude e' of the voltage oscillation produced by the third class conductor, is approximately inverse proportional to the resistance of the oscillating circuit. (As seen by equation (**37**)).

V. Instances

(1) Spark discharge on high-voltage coil of 60,000 volt 3000-kw. 60-cycle power transformer.

Let the constants be:

r = 6 ohms, or about 0.5 per cent resistance of the coil

L = 0.1 h, or about 3 per cent reactance

C = 0.0001 mf.

L_0 = 0.6 h, or about 20 per cent reactance of supply circuit

r_0 = 40 ohms, or about 3⅓ per cent resistance of supply circuit

f_0 = 60 cycles, thus $q_0 = 2\pi f_0 = 377$

E_0 = 60,000 $\sqrt{2}$ = 85,000 volts.

Assuming $\delta = 60$ deg. as time lag at the oscillation frequency.

It is then, by equations (**35**) to (**37**):

$q = 316{,}000 = 837\, q_0$
$f = 50{,}300$ cycles
$x_0 = 226$ ohms
$q\, L = 31{,}600$ ohms
$k = 26{,}600{,}000$ ohms

Assuming the effective resistance of the oscillating circuit increased to 10 times the ohmic resistance, by the energy losses in the insulation etc. at the high frequency, that is:

$r = 60$ ohms.

and assuming stationary conditions reached by the transient effective resistance of the spark discharge having dropped to equality with the ohmic resistance, that is:

$$r_1 \cos \delta = 60, \text{ and } r_1 = 120 \text{ ohms}$$

this gives:

$\alpha_0 = 62$ deg.

and, denoting:

$\varphi = q_0\, t$, gives:
$e_0 = 85{,}000 \sin (\varphi + 62.)$
$e_1 = 47{,}000 \sin \varphi \{1 + \sin (837\, \varphi - 60.)\}$
$i_1 = 392 \sin \varphi \{1 - \sin 837\, \varphi\}$
$i = 392 \sin \varphi \sin 837\, \varphi$
$i_0 = 392 \sin \varphi$
$e' = 47{,}000 \sin \varphi \{1 - 263 \cos 837\, \varphi\}$

or a maximum value of the condenser voltage of over 12 million volts.

Obviously, no such voltage is reached, but the insulation destroyed before the cumulative oscillation is built up to full value.

(2) Arcing ground on 30 mile three phase transmission line supplied with 30,000 volts, 60 cycles from generator and step up transformer.

Let the constants be:

$r = 4$ ohms
$L = 12$ mh.
$C = 0.3\ \mu$f
$L_0 = 0.2$ h.
$r_0 = 6$ ohms
$f_0 = 60$ cycles, thus $q_0 = 377$
$E_0 = 30{,}000 \sqrt{2} = 42{,}500$ volts.

Assuming $\delta = 45$ deg. as time lag at the oscillation frequency.

It is by equations (**35**) to (**37**):

$q = 16{,}500 = 44\, q_0$
$f = 2640$ cycles
$x_0 = q_0\, L_0 = 75.4$ ohms
$q\, L = 198$ ohms

$$k = \frac{1}{q_0\, C} = 8800 \text{ ohms}$$

Assuming as effective resistance of the oscillating circuit at 2640 cycles, twice the ohmic value, or:

$r = 8$ ohms.

gives as limiting value of the transient effective negative resistance.

$$r_1 \cos \delta = 8, \text{ and } r_1 = 11.3 \text{ ohms}$$

This gives:

$\alpha_0 = 81.5$ deg.

and, denoting:

$\varphi = q_0\, t$; gives
$e_0 = 42{,}500 \sin (\varphi + 81.5 \text{ deg.})$
$e_1 = 6300 \sin \varphi \{1 + \sin (44\, \varphi - 45 \text{ deg.})\}$
$i_1 = 560 \sin \varphi \{1 - \sin 44\, \varphi\}$
$i = 560 \sin \varphi \sin 44\, \varphi$
$i_0 = 560 \sin \varphi$
$e' = 6300 \sin \varphi \{1 - 19.2 \cos 44\, \varphi\}$

or approximately:

$e' = 120{,}000 \sin \varphi \cos 44\, \varphi$

That is, the arcing ground in this case produces a continuous oscillation which builds up to nearly three times the normal line voltage.

It is interesting to note that the cumulative surge of the arcing ground in a transmission line does not reach such excessive values as that in the high-voltage coil of the power transformer, but may be of moderate intensity, of the magnitude of the normal line voltage.

RADIO STANDARDIZATION

At the request of six radio organizations, the Bureau of Standards, in cooperation with the American Engineering Standards Committee, called a conference on radio standardization which met in New York, January 12. Over 100 persons were present representing nearly that number of different associations, manufacturers, dealers, operating companies, and other organizations interested in radio.

Dr. F. C. Brown, Acting Director of the Bureau of Standards, presided over the conference. Many important points were discussed, and it was voted that action should be taken toward the formulation of standards of radio apparatus and service and that a single broadly representative national committee should be organized, following the American Engineering Standards Committee procedure, for dealing with all phases of radio standardization, including commercial standardization, methods of measurement and testing, and nomenclature. It was voted to request the American Institute of Electrical Engineers and the Institute of Radio Engineers to accept joint sponsorship for this Sectional Committee.

It was also voted that the national committee should determine immediately the type and scope of standardization to be undertaken, including a consideration of testing facilities and other related lines of activity. Mr. L. T. Robinson, representative of the American Institute of Electrical Engineers, and Dr. A. N. Goldsmith, Secretary of the Institute of Radio Engineers, selected an advisory committee of thirteen to assist in the organization of the national Sectional Committee and necessary technical subcommittees.

Lightning Disturbances on Distribution Circuits

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Review of the Subject.—*A general survey is presented of the nature and distribution of failures and interruptions due to lightning upon the circuits of a large city supply system. Recommendations are given for improving conditions without specifying particular makes of arresters, in recognition of the fact that a considerable number of different types is proving adequate to meet the conditions imposed upon them on the moderate voltage systems under consideration. The subject is treated under three principal divisions: 1st. Troubles on 115-230 volt distribution circuits. 2nd. The 2300 volt circuits, and 3rd. The 13,200 volt circuits. It is shown that line failures on the low-voltage circuits are so infrequent as to be practically negligible, and that the blowing of fuses and injuries to other parts of the equipment on customer's premises are infrequent except in the case of house meters. A considerable number of meter burn outs are recorded, and it is shown that trouble from this source increases with the length of the secondary circuit. To guard against future trouble, especially as secondary networks are developed, it is recommended that a simple spark gap or other equivalent type of arrester be installed at the customer's premises as a part of the equipment in his service box. For the 2300 volt circuits, it is found that lines which run over high ground and open country are more exposed to transformer burn outs and the blowing of transformer fuses than lines in the built-up sections where buildings screen the circuit. Also, that the amount of damage to the exposed lines decreases as the number of arresters increases and that a transformer directly protected by an arrester is in a very large measure guaranteed against complete breakdown and to a less extent against the blowing of its fuses from lightning. Also, that the effectiveness of this protection is decreased with high resistance in the ground connection. Finally, for the 13,200-volt aerial circuits, it is shown that on lines at a considerable distance from generating points most of the damage from lightning is in insulator breakages and without interruption to service, but where line reactance is not sufficient to prevent flow of heavy dynamic current at the time of discharge, the conductor is often fused allowing the line to fall. To guard against these troubles, arresters should be distributed along the line at not more than two mile intervals and near generating stations the three arresters of a group should be mounted on successive poles and provided with independent ground connections.*

* * * * * *

THE investigations which form the basis for this paper were made upon the Philadelphia Electric Company's system during the summers of 1921 and 1922. As lightning disturbances show so many eccentricities and as each storm has its own individuality both as to its path over the system and as to the intensity of its activity, it is necessary, in a study of this nature, to consider a great mass of data and at the same time analyze many individual cases, before any generalizations can be made.

The work was classified under three main divisions:

I. The low-tension distribution system, mainly 115-230 volt, three-wire single-phase with neutral grounded.

II. The main primary distribution system, 2300 volts, three-wire two-phase ungrounded.

III. The high-tension system, 13,200 volts, three-phase with neutral grounded at the generating stations only.

I. Failures on the Low Tension System

It will probably be rather generally conceded by distribution engineers that lightning troubles on the low-tension system are of comparatively infrequent occurrence and of a much less serious character than those on other parts of the system. It was thought best, however, in these investigations, to obtain some quantitative results from lightning failures on these low-voltage circuits; both for the lines themselves and for the apparatus upon the customer's premises. Considering first-line failures, records were obtained for the storms occurring upon June 3rd and 10th, and July 1st and 12th, 1922, which were found to be sufficiently widespread and severe to be fairly typical. The linemens' reports upon circuit failures during these storms were, therefore, investigated, and it was found that they reported no insulator failures upon the low-voltage circuits and only three cases of low-voltage lines being down; one of these being due to a tree falling upon the circuit. On a system as extensive as the one under consideration this amount of injury could readily be passed over without further investigation.

At first sight the record of failures upon customers' premises did not offer a very encouraging field for analysis. The three classes of failures which might in some cases have been caused by lightning were the blowing of fuses, injuries to house fixtures and to meters. Monthly totals for each of these were recorded. If any considerable number of house fuses had been blown by lightning disturbances, this fact was completely masked by the large number blown by other causes. The totals ranged from 4000 to 5500 and were in some cases greater for winter months than during the lightning season. The number of injuries to house fixtures never reached 150 per month and they were quite irregularly distributed. There was, however, distinct evidence that a majority of the meter burn outs might have been due to lightning as there was a large increase in the number of such failures during the summer months. More specific information regarding these failures was therefore sought by obtaining a record of all meter repair orders issued on the days of the four storms referred to above, and upon the day following each storm. By this method a few meters might have been included which had not failed from lightning, but there could not have been enough of them to appreciably effect the results. Also, it was not possible to locate all of those which were

injured by lightning for it was necessary to rely upon the customer for reporting the trouble and if the house was closed at the time, or if the failure did not interrupt the service, the injury would not be detected until it was too late to determine with certainty the cause of the failure.

Consideration should first be given to the geographical distribution of these meter failures, especially in comparison with the disturbances which occurred on the primary circuits during the same storms, as shown from the record of the blowing of transformer fuses. Both of these classes of failures were located on a pin map, but the comparison shows up more distinctly in Fig. 1, which gives the number of failures in parallel strips of territory 2500 feet wide running across the city from east to west. The few failures which occurred in West Philadelphia are not included as they were too scattered to have any significance and by their omission a truer picture can be obtained of conditions in the central and southern portion of the city where underground distribution is largely employed.

The most striking feature of this diagram is the comparative immunity from lightning troubles that is

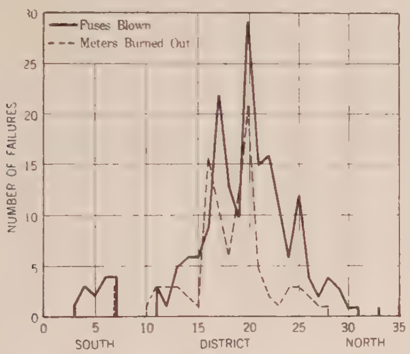

Fig. 1

shown for the secondary circuits in the northern sections of the system which comprise Tacony, Germantown, Chestnut Hill and the outlying territory. This is the more remarkable when it is known that in previous years the primary circuits in these sections had suffered so severely that it had been necessary to provide much more liberal lightning arrester protection there than in any other parts of the system. No such protection had been found necessary for the secondary circuits. It is evident, therefore, that mere geographical location within the area of maximum lightning disturbances is not the determining factor in causing failures in these low-tension circuits. A hint for the solution of this problem may be obtained from wireless practise where the design of the aerial controls so largely the ability of the station to pick up distant signals. Upon this basis the explanation for the absence of meter failures in the northern territory was sought by comparing the relative lengths of the secondaries. An inspection of the secondary circuit diagrams showed that throughout this territory a majority of the customers are served from separate transformers having short secondary taps, and even where several services are run from one transformer the secondary circuits are shorter than those which prevail in the more congested districts. In order to check this theory further the meters which failed during the storms mentioned above were identified with the circuits which served them, and, except for two questionable cases where the addresses were not clearly given, all of the 105 failures were on circuits of approximately 1000 feet or more in length.

This investigation also brought out the fact that in only two cases were meters which failed connected to transformers on which the fuses were blown during the same storm, and in no cases were such meters connected to transformers which were burned out by lightning. Thus all the evidence points to the fact that the lightning disturbances in the secondary circuits are not transmitted from the primaries through the transformers, but originate in the secondaries themselves and are controlled largely by the length of these circuits.

The losses occurred indiscriminately upon meters connected to ungrounded circuits or circuits grounded outside the premises or directly at the meter. No true perspective upon the protective value of these methods of connection was obtained, however, as the relative number of meters using each type of connection was not known.

On a system containing over 240,000 meters a record of 105 failures during four of the most severe storms of the season does not appear very serious and yet, in view of the efforts that are constantly being made to minimize interruptions to service, it does seem as though these conditions might be improved. Possibly the correct solution is to provide heavier insulation for the meters, but it is questionable whether, if the meters cease to function as lightning arresters, more serious damage and even loss of life may not result from lightning reaching the house circuits. Furthermore, as the load density increases, the tendency is toward the use of longer secondaries which should ultimately lead to the development of an interconnected system similar to the Edison direct-current network. In that event, these records indicate that much more serious lightning trouble may be expected.

It is known that on other systems a good deal of trouble is being experienced from meter burn outs, but the writer has been unable to obtain any data upon the extent of such damage nor whether measures are being taken to correct it. On the large city systems, at least, it would seem desirable to introduce some form of lightning protection on the secondary circuits which could be gradually extended over the system. A spark gap, or one of the other types of low-voltage arresters, should prove adequate if properly distributed. The best place to locate the arrester is on the customer's premises and it could properly be included as part of the necessary equipment of his service box. A suitable ground connection is available at this point and very little additional expense would be entitled.

II. The 2300 Volt System

The consideration of lightning troubles upon these circuits was confined to a study of transformer failures and the blowing of transformer fuses. A general survey of transformer burn outs was undertaken during the summer of 1921. It appeared necessary to cover as large a number of cases as practicable, in order to eliminate the effect of the irregular distribution of individual storms, so that the study was based upon the records of failures from January 1st, 1920 to August 1st, 1921. As these records did not specifically indicate the cause of the failure, it was assumed that all transformers removed from the line on the day of a storm or on the following day had failed from lightning. Eighty-six transformers were so removed from the aerial lines during 1920 and forty transformers up to August 1st in 1921. This represents about one third of the total number of transformers removed from these circuits for all causes during this period, and, while it may include a few transformers which were not injured by lightning, the number cannot be sufficient to alter the conclusions reached, although it may account for some of the eccentricities which appear in the records. A further

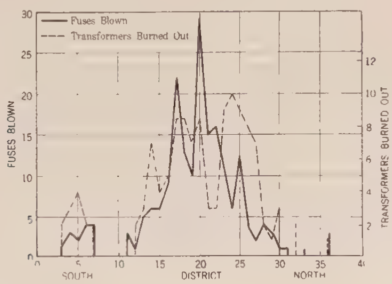

Fig. 2

check upon this method of selection was obtained for transformers which failed from lightning from August 1st, 1921 to August 1st, 1922, by having the linemen report such cases immediately after each electric storm. In this way questionable cases should be eliminated, but the results shown for failures during the later period are entirely in harmony with the conclusions reached from a study of the earlier records.

The one hundred twenty-six transformers which failed from lightning from January 1st, 1920 to August 1st, 1921, were located geographically and their distribution is shown in Fig. 2. The transformers were also identified with the circuits to which they were attached and it was found whether or not they were protected with lightning arresters. In order to obtain a proper perspective of this phase of the subject, the length of all the aerial circuits of the system was recorded, together with the number of arresters and transformers connected and the number of transformer failures. This information is given below.

In some respects the records appear erratic, as should be expected in a study of lightning disturbances, though it is believed ,as already noted, that some irregularities are due to errors in the records and some possibly to not having covered a sufficiently long period in the investigation. Nevertheless, the following facts are clearly brought out:

1. Circuits which have the greatest amount of lightning protection suffer less than circuits in the same district with less protection.

2. During 1920 and 1921, the Tacony District suffered more severely than any other section of the system, and the greatest losses occurred on the circuits which had the least protection.

3. Large sections in the central part of the city, which had very little arrester protection, experienced no tranformer losses.

4. A large number of circuits in different parts of the system should have additional protection.

The following information is submitted in confirmation of the above statements:

1. The circuits which have the greatest number of arresters per unit length of circuit in order of their protection are *C H*-1, *C H*-3, *T A C* 1 & 4, *F I L*-2, *G T N*-4, *F I L*-10 and *G T N*-1. These have from three to four arresters per mile of line. There are 437 transformers connected to these lines and only one loss was reported for each year for the entire group, although before the arresters were installed Chestnut Hill and Germantown suffered most severely from lightning. *C H*-4 and *G T N*-2 each are protected with about one arrester per mile and the former of these lost four transformers and the latter five, which is greater than any other circuit outside of Tacony. The exceptional feature in these records is that *G T N*-3 and 5 with about the same protection suffered no losses.

2. At the other extreme *T A C*-2, which is a very long line feeding all the territory north and west of Tacony, is very much exposed to lightning and is protected with only one arrester per seven miles of line, which means that long sections have no protection. There are 222 transformers on this circuit and 13 of these failed in 1920 and 14 in 1921. *T A C*-6 has no arrester protection, but in places is less exposed than *T A C*-2, and this has lost a total of seven transformers for the two years out of a total of 60 connected. *T A C*-3, with about the same arrester protection as *T A C*-2, but with much greater natural protection, lost three transformers out of 62. The other Tacony circuits have more arrester protection and pass through thickly settled sections. None of these have lost more than one transformer.

3. For the last year and a half no failures due to lightning have been recorded for any of the circuits out of Ludlow or Columbia substations and only two from Marshall. One of these was a 37½ kv-a. transformer which had been in service only a month and was replaced by a 50-kv-a. suggesting that the failure had been due to overload rather than lightning. There are twelve circuits from Susquehanna, eight from Ontario and four from Hunting Park, for which no losses are recorded for this period. It is too much to expect that

this perfect record will be maintained indefinitely, and it may be that a storm of unusual severity passing over this section may disclose points where additional protection should be provided, but the records cover a sufficiently long period to prove that very little lightning trouble need be expected in this territory.

4. Other circuits pretty generally distributed over the system show losses of from one to three transformers per circuit which is not sufficient to serve as a guide in locating additional arresters, but does suggest that such protection should be provided. Here the danger of basing a judgment upon inadequate data is well illustrated by the record of failures in West Philadelphia and South Philadelphia. In 1920 it seemed as though the former was much better protected than the latter, but in a single storm on the night of July 15th, 1921, eight transformers were lost in West Philadelphia and only one has been reported for South Philadelphia for this year. This failure appears to have been due to a direct stroke as the pole which carried the transformer was also injured.

A further indication of the effectiveness of arresters in the protection of these circuits is brought out by the fact that out of the total of 126 transformers which had failed from lightning, only five were directly protected with arresters, and in only one other case, a 4-kv-a. near Tacony, was there clear evidence of a failure near an arrester and this line was unprotected for a long distance on one side of the transformer. The question is frequently raised as to the part the ground resistance plays in the proper functioning of an arrester and, in order to determine whether faulty ground connections might not have been responsible for the failure of these arresters, resistance measurements were made at each of the arresters and at a number of others on the same circuits in their immediate neighborhood. In one case the ground resistance of the faulty transformer was 102 ohms and on four others near it, it ranged from 47 to 120 ohms. In another case the ground resistance was 227 ohms and on three others in the neighborhood it ranged from 70 to 167 ohms. In the third case the ground resistance was 253 ohms, while on five others in the vicinity it ranged from 27 to 77 ohms. In the last two of the five failures, it measured 364 ohms and 477 ohms respectively, and other ground resistance measurements in the same vicinity showed about the same values. It will be seen that in all but one of the cases of failures the resistance was over 200 ohms, and there the spring clip connection to the ground wire was so loose that there is no assurance that it had not fallen entirely out of place at the time of the storm. The resistance of this connection on the day the tests were made was 44 ohms. Measurements on other clips showed no appreciable resistance. It should be noted in this connection that it is difficult to obtain low-resistance grounds in much of the territory north of the city on account of the high, rocky nature of the soil.

Summarizing the above results, it appears that the arrester protection which has been provided on the most exposed circuits in Chestnut Hill and Germantown are proving successful in minimizing lightning troubles, though not completely eliminating them from these circuits. Also, it is seen that in the few cases where transformers which had arrester protection are burned out, the ground resistances were abnormally high on account of the rocky nature of this region. It is further shown that other circuits, especially in the Tacony district, needed additional protection. As noted below, the arresters which were installed in 1922 on these circuits have proved effective in reducing the losses in this territory.

It may be interesting to note that while the experience in Philadelphia as to the effectiveness of arresters in protecting transformers is in full harmony with the results obtained by Mr. D. W. Roper in Chicago (A. I. E. E. PROCEEDINGS, Vol. 35, page 655), there are other respects in which the lightning appears to affect the circuits differently in the two cities.

Transformer Fuses Blown.—Comparative figures are given below for the total number of transformer fuses blown on the 2300-volt aerial circuits by months:

	1921	1922
January	15	55
February	30	33
March	38	47
April	33	40
May	56	65
June	251	178
July	446	208
August	84	211

The increase in failures during the summer leads to the presumption that the great majority of these fuse failures are due to lightning and the improvement in the records for 1922 may be ascribed to the fact that during this year about 500 additional lightning arresters have been installed on the more exposed circuits in the northern part of the system. The balance of the failures, due to overloads on the transformer, falling of trees on the circuits, or the falling of the circuits themselves on account of ice load, wind, etc., could probably have been reduced in number if the transformers had been more heavily fused. The present practise is to fuse on the basis of one ampere of fuse capacity per kv-a. of transformer rating, five ampere fuses being the smallest in use. As the principal function of the fuse is to clear the line in case of a transformer failure rather than to protect the transformer, it should be entirely feasible to make a general increase in fuse capacities. This would be in line with the practise of many of the large operating companies. There is nothing in the records to give a clue to the probable decrease in the number of fuses blown if this practise is adopted. The really important phase of the problem is to consider how to minimize the blowing of fuses during electric storms.

As already indicated, this trouble cannot be due, except in rare instances, to lightning disturbances in the

secondary circuits, for direct evidence shows that lightning surges on the secondaries, as indicated from the burning out of house meters, is not associated with primary failures, either with the blowing of fuses or the burning out of the transformers. The cause of the fuse failure must therefore be localized at the transformer itself. It is apparently due to a flashover across the transformer surfaces or in the primary coils, the insulation being reestablished, at least in part, after the blowing of the fuse has extinguished the arc.

Further information upon these fuse failures was obtained by definitely localizing with their circuits the 112 failures which occurred during the four storms in June and July, 1922, to which reference has already been made. For comparison with transformer burn outs the distribution of these failures is shown in Fig. 2. It is seen that they follow much the same course as the transformer burn outs as should be expected. The agreement would probably have been closer if the same lightning period had been considered in the two cases. The divergence which is shown for the northern territory for instance, may be explained by the large increase in the number of lightning arresters installed in this district between the periods covered by the two sets of records.

The records for these four days showed that in 17 cases fuses blew on the same transformer in two or more successive storms, and in several cases later records indicated that ultimately the transformer broke down permanently. It is evident, therefore, that the blowing of transformer fuses is serious, not only for the interruptions which they cause to the service, but also for the deterioration in transformer insulation which they indicate.

As the lightning disturbances which causes a fuse to blow comes in over the primary, the arrester protection which may be justified purely in saving the transformer from burn out, should also prove effective in reducing the trouble from the blowing of transformer fuses. Unfortunately, this investigation does not indicate that the same measure of protection may be expected in the two cases. The records collected during 1922 showed that in only five cases were transformers burned out which were protected by arresters and in one of these a very old type of arrester was employed which was probably not operative at the time. On the other hand, during the same period, 30 cases were recorded where arrester protection was not effective in preventing the transformer fuses from blowing. Apparently in all but very exceptional cases the arrester carries off a sufficient amount of the energy of the lightning surge to keep the transformer from complete failure, but in some cases it allows enough energy to pass to temporarily break down the insulation until the blowing of the fuse clears the circuit. This points to the importance of obtaining low ground resistance for the arrester in order that it may deflect as much of the lightning discharge as possible. As already noted, it is very difficult to obtain this in certain of the outlying sections of the system. It is believed, however, that this investigation shows conclusively that with the present installation, transformer failures from lightning are being kept within remarkably low limits and the blowing of transformer fuses in being minimized.

III. The 13,200-Volt System

The 13,200-volt circuits of this system are, in the majority of cases, underground, and serve as feeders from generating stations to substations. There are, however, a number of aerial circuits operating at this voltage which feed substations in the outlying districts, and others which supply large power customers. The latter are increasing in number and importance each year.

A group system of numbering has been adopted to indicate in general the geographical location of the circuit. Circuits No. 704 to 706 run on the same pole line from Tacony westward, eventually separating to feed railway substations in the northern territory. Circuit No. 708 follows the river from Tacony to Bristol. Circuit No. 1126 runs from Hunting Park substation to Manayunk. Circuits No. 1301 to 1305 interconnect the above mentioned railway substations and tie in with the Chestnut Hill substation. Circuits No. 2101 and 2102 run practically from the Schuylkill Generating Station to the extreme southern portions of the city. Circuit No. 2118 is located in Frankfort which is nearer the Delaware Generating Station than Tacony. Circuit No. 2301 serves a group of manufacturing plants north of Tacony. This completes the list of circuits in operation during 1921, which was the period covered by the investigation. The general practise has been to protect these circuits at the substations by electrolytic arresters and at customers' taps by spark gap arresters.

The company's records give definite information upon the number of interruptions of each of these circuits during electric storms, and in every case where it has been possible to locate the cause of the interruption, this has been given, together with the exact location of the trouble and the extent of the damage done. There is also very clear indication that lightning was responsible for many injuries to insulators, pins and cross arms, which did not interrupt the service. These injuries were detected by the linemen who patrol the circuits after each storm and at stated intervals throughout the year. It is unfortunately impossible from the nature of these reports to differentiate between failures from lightning and from other causes. It is found, however, that there are fully three times as many insulator failures on these circuits during the lightning season as in the winter months. As most of the insulator breakages in winter are probably due to ice or high winds and failures from such causes must be less in summer, it appears conservative to assume that at least two thirds of the insulator breakages during the year are due to lightning. The reports give the number of repair jobs at each pole

rather than the number of insulators replaced, so that the actual number of insulator failures will be greater than the figures given below. From the mass of data contained in these reports, the following information has been selected as it is believed that it is adequate to give a fairly clear representation of the character and extent of the damage done to these circuits by lightning during 1921:

Circuit	Length in miles	Interruptions during storms	Number of Repair Jobs: On insulators	Number of Repair Jobs: On cross arms and Pins	Interruptions per mile	Insulator repairs per mile
704	8	3	28	2	0.37	3.5
705	6	1	6	1	0.13	1.0
706	7	3	21	6	0.43	3.0
708	9	1 intermittent	3	0	0.11	0.3
1126	4	1	1	0	0.25	0.25
1301	7	2	27	6	0.29	3.9
1302	3½	1	18	3	0.29	5.1
1303	5	0	9	5	0	1.8
1304	6	0	6	1	0	1.0
1305	4	0	10	8	0	2.5
2101	9	6	12	3	0.66	1.4
2102	8½	8	14	1	0.94	1.6
2118	1½	4	0	0	2.6	0
2301	1¾	0	1	0	0	0.6

The records of failures on these circuits as given above show the customary freakishness of lightning and undoubtedly do not cover a sufficiently long period to bring out many of the peculiarities of the individual circuits. There are, however, certain features of the records which should be noted. In the first place, it appears that the circuits most distant from generating points, such as No. 1301-5, had a great many insulator failures but were remarkably free from interruptions during electric storms. Circuits somewhat nearer the center of the system such as No. 704 and 706 had much the same record of insulator failures, but experienced a greater number of interruptions. The circuits in South Philadelphia Nos. 2101-2102, which are still nearer large generators, had fewer insulator failures, but most of those which occurred during storms were accompanied with serious line trouble. It should furthermore be noted that the records of lightning trouble on 2300-volt circuits, which are much more complete than for 13,200-volt circuits, show that all through the territory north of the city, the injury from lightning to apparatus unprotected by arresters was much greater than in South Philadelphia. It is reasonable to suppose, therefore, that these 13,200-volt circuits in the Northern District had had many lightning surges induced in them which discharged themselves over insulators without completely breaking these down, the high line reactance in such cases limiting the dynamic current to comparatively low values. However, when such surges occur on circuits where the line reactance is low as on No. 2101 and 2102, the dynamic current which accompanies a discharge generally destroys the insulation and the arc which follows burns off the conductor, allowing the circuit to fall. Short circuit conditions on No. 2118 are about as severe as on No. 2101 and 2102, though the latter has much better natural protection. Three of the four interruptions recorded for this circuit were accompanied with falling of the conductors. In these cases spark gap arresters near the points of trouble failed to protect. There were only three cases recorded in 1921 in which the circuits north of this point fell during electric storms. In one case there was a direct stroke on No. 705 outside the Oxford Substation, in another both No. 704 and 706 were down at the same pole, and in the third case, one span of No. 1301 fell near the Chestnut Hill Substation. It should be noted that in the two latter cases the failures occurred near the feeding end of the circuit where the dynamic current, which might develop on short circuit, would be a maximum.

Attention should be called to the relatively good records of Nos. 705 and 708. No explanation was found for this condition on No. 705 for it is just as much exposed as No. 704 and N0. 706 being on the same pole line for most of the distance, and the circuits are transposed so that there should be no advantage of position. Circuit No. 708 had formerly been subjected to so many interruptions that it was completely re-insulated, 22,000-volt insulators being used in place of the lower voltage type employed on the other circuits and this undoubtedly accounts for the improved performance of this circuit.

Two general methods suggest themselves for reducing lightning troubles on these 13,200-volt circuits. Either to reconstruct the circuits with 22,000-volt insulators, as has been done with good results on circuit No. 708; or provide some form of lightning arrester protection on the lines themselves in addition to the arresters already in use at the terminals. The first method would involve considerable expense and while it might be employed advantageously at certain of the more exposed portions of the system, the more direct and satisfactory method would be to relieve insulation stresses by providing suitable discharge paths to ground through lightning arresters. This would in general require that the arrester should be suitable for pole mounting. On the circuits in the outlying districts at a considerable distance from the generating points there should be no difficulty in providing at reasonable expense, suitable protection by the use of spark gap or other compact form of arrester, distributed at about two mile intervals on the average.

The general opinion among operating engineers appears to be that the electrolytic or oxide film arresters are the only types so far developed which can satisfactorily resist the tremendous dynamic discharge which may develop near large generating units.[1] The high first cost of such arresters and the difficulty in properly distributing them along the right of way, presents a serious problem in providing suitable protection for these high-voltage circuits leading out from

1. N. E. L. A. *Proceedings*, 1921, p. 700.

DATA UPON 2300 VOLT CIRCUITS

Circuit	Length of wire in 1000 ft.	Lightning Arresters		Transformers			
		Total	Per 10,000 ft.	Pro-tected	Total	Lost by Lightning 1920	Lost by Lightning 1921
Tacony							
1 & 4	18	15	8.3	8	8		
2	533	14	0.2	5	222	13	14
3	134	3	0.2	0	62	2	1
6	193	0		0	60	4	3
7	73	3	0.4	0	39	1	
8	60	6	1.0	1	38	1	
9	65	3	0.4	0	33		1
10	90	3	0.3	2	53		
11	99	4	0.4	2	42		
12 & 13	72	6	0.8	0	22		
Chestnut Hill							
1	230	216	9.0	80	110	1	
2	157	86	5.5	40	43	2	
3	169	148	8.7	69	73		
4	178	38	2.1	11	47	3	1
Germantown							
1	45	28	6.2	14	22		
2	235	47	2.0	16	56	3	2
3	105	23	2.2	8	48		
4	65	58	7.4	27	41		
5	70	11	1.6	7	10		
Filbert							
1	39	14	3.6	1	12		
2	152	125	8.2	50	59		1
3	111	13	1.2	2	42		1
4	77	4	0.5	2	40		1
5	111	23	2.1	4	63	2	
6	63	17	2.7	8	22		1
7	80	20	2.5	9	48	2	
8	65	7	1.1	2	31	1	
9	69	9	1.4	3	60		
10	288	195	6.8	91	124		
11	92	9	0.1	3	31		
12	84	15	1.8	3	17		
13	66	2	0.3	1	21		
14	52	3	1.4	3	60		
15	63	7	1.1	2	24		1
16	72	19	2.6	11	27		
Paschall							
1	93	16	1.7	4	43	1	
2	69	2	0.3	1	14		1
3	82	2	0.2	2	31	1	3
4	84	8	0.9	3	59	1	
5	54	4	0.7	2	30		
6	54	7	1.3	3	27		
7	60	2	0.3	1	19	2	
Hunting Park							
5	140	20	1.4	12	50		
6	140	19	1.3	10	75	3	1
7	69	9	1.7	3	18		
8	90	8	0.9	5	51	1	
9	102	3	0.3	6	55	1	
10	108	9	0.8	3	35	1	
11	132	4	0.3	2	58	2	
12	210	0		0	45	1	1
13	136	2	0.1	2	48	1	
14	99	3	0.3	2	40	1	1
15	27	3	1.1	2	8		
16	24	0		0	9		
17	66	0		0	35	1	1
18	27	0		0	11		
19	102	2	0.2	1	40		1
20	81	5	0.6	2	48	2	
Ontario							
1	36	0		0	18	2	
2	70	3	0.4	2	29	1	1
3	117	0		0	37		
4	27	0		0	9		
6	98	0		0	24	1	
7	51	4	0.8	2	38		
8	90	0		0	63		
9	63	0		0	37		
10	16	0		0	3		
11	50	0		0	12		

DATA UPON 2300 VOLT CIRCUITS (*Continued*)

Circuit	Length of wire in 1000 ft.	Lightning Arresters		Transformers			
		Total	Per 10,000 ft.	Pro-tected	Total	Lost by Lightning 1920	Lost by Lightning 1921
12	84	0		0	38	1	
13	84	0		0	56	1	
14	36	0		0	14	1	
15	48	0		0	27		1
16	12	3	2.5	4	6		
Susquehanna							
1	58	7	1.2	3	40		
2	46	6	1.4	2	4		
3	36	6	1.9	2	11		
4	26	6	2.3	14	14		
5	26	0		0	12		
6	90	3	0.3	2	38	3	
7	65	6	0.9	2	37		
8	20	0		0	9		
9	82	6	0.7	4	37	1	
10	30	0		0	16		
11	57	7	1.2	4	32	1	
12	63	0		0	36		
13	19	0		0	6		
15	57	3	0.5	2	44	2	
16	60	0		0	28		
17	36	5	1.4	4	32		
Marshall							
1	18	6	3.3	0	20*		
2	33	6	1.8	7	33	1	
4	38	6	1.5	0	38	1	
5	27	5	1.9	4	16		
6	55	18	3.2	10	56		
7	45	6	1.3	5	20		
8	36	3	0.9	0	14		
9	12	6	5.0	0	0*		
10	9	8	9.9	3	5		
11	30	6	2.0	10	35		
12	21	0		0	28		
13	45	0		0	39*		
Columbia							
1	underground						
2	24	6	2.5	8	21		
3	60	5	0.9	2	39		
4	42	3	0.7	0	17		
5	27	6	3.1	3	17		
6	45	7	1.7	3	32		
7	42	3	0.7	0	20		
8	30	6	2.0	4	8		
9	underground						
10	27	0		0	21*		
Ludlow							
1	42	3	0.7	0	34		
2	13	0		0	11		
3	21	0		0	11*		
4	60	7	1.1	4	34*		
5	underground						
6	21	0		0	25*		
7	39	3	0.8	1	37		
8	underground						
Carpenter							
1	117	5	0.4	3	40	1	
2	105	6	0.5	1	21	2	
3	underground						
4	65	0		0	33		
5	48	0		0	19	1	
6	underground						
7	92	3	0.3	1	53	3	1
8	96	6	0.6	0	61		
9	104	0		0	55	1	
10	40	0		0	6		
11	30	0		0	6		
12	120	6	0.5	8	40		
13	111	0		0	39	1	
14	reserve						
15	112	0		0	51	2	
16	108	0		0	61		
17							
18	16	0		0	6		

*Subway type omitted.

generating points. An inspection of some of the spark gap arresters which had failed suggested that possibly this trouble might be caused by a short circuit between phases due to the simultaneous discharge of two or more of the arresters of the group. In was therefore proposed by Mr. H. S. Phelps of the Philadelphia Electric Company, to mount the three arresters of one group upon successive poles and provide independent grounds, thus introducing twice the ground resistance between phases at the time of discharge. Three groups of arresters arranged on this principle were installed on July 1st of this year on the most exposed portions of circuits No. 2101 and 2102. The day after their installation a storm of unusual severity passed over these circuits. Lightning struck an oil tank within a few rods of the circuits, fuses were blown on a transformer connected to a 2300-volt circuit on the same pole line, and other damage was done in the neighborhood, but the arresters functioned satisfactorily and no damage was done to these circuits. The record for the rest of the summer has been equally satisfactory. The question still remains whether longer experience will justify the hope that this method will provide adequate protection for such circuits and there is the further question as to what is the minimum reactance which must be provided between such arresters and the generating units in order to insure proper performance.

FARM ELECTRIFICATION IN SWEDEN

Rural districts in many foreign countries, and especially in Sweden offer many possibilities for the use of electricity, according to an article in *Commerce Reports*. Where the land is worked in large holdings the demand is for isolated plants, which may range in capacity from ½ kw. to 50, or even 100 kw. Where the rural districts are highly cultivated and thickly settled, the tendency is to build distribution lines out from near-by central-power systems and give farmers electric service on much the same terms as dwellers of the cities.

Where small farm lighting plants are installed general use of electricity is hardly possible, since in most cases the sets have not capacity enough to supply more than the necessary lighting. Real rural electrification, therefore, takes place when electric-power lines are built out through country districts of sufficient capacity to supply not only the lighting needs but all the power requirements of the farm. Sweden probably has made greater progress along these lines than any other country, and according to a recent report submitted by Consul Walter H. Sholes, Goteborg, the electrification of tilled ground in Sweden increased from 6.4 per cent to 38.5 per cent during the five-year period from 1917 to 1921.

Consul Sholes reports:

Already one-third of the country devoted to agriculture is on an electrical basis, according to official reports. This, perhaps, is only natural in a progressive country like Sweden, which is in most parts a hilly country, with plenty of water power. The war undoubtedly furnished the impetus to the electrification of Sweden. When no petroleum could be obtained farmers had to sit in the dark during the long Swedish winter, until acetylene lamps appeared in the market. Electric light, however, soon followed, as farmers began to realize the importance of hydroelectric power. Only the high prices heretofore prevailing have retarded the general adoption of electric power in rural districts.

The Government of Sweden is assisting the electrification of rural districts by granting loans from the power-transmission fund. These loans are given to power-distribution associations organized somewhat as local cooperative associations and covering, say, a parish. These associations generally buy power in bulk at 1500 to 3000 volts, and then build the local lines as needed. Both direct and alternating current are used on the farms themselves, and possibly the most common system is 220 volts, four-wire, three-phase, with 127 volts for lighting. There is a considerable amount of 380-volt, four-wire, three-phase service, with 220 volts for lighting. Three-phase transformers are used and a great deal of iron wire is employed for the distribution lines. Where direct current is employed, 110 or 220 volts is generally used for lighting and 220 or 440 volts for power.

In the electrified districts of Sweden electric power is used for every possible purpose, including threshing. Considerable study has been given even to the application of electric power to plowing, with more or less success. Where equipment is too expensive to be bought by individual farmers, community-ownership arrangements have been developed satisfactorily.

While rural electrification in Sweden has, on the whole, worked out successfully, it is nevertheless true that during the war the pressure under which the work was done and the lack and high cost of proper materials, resulted in expensive work and systems which were not as efficient as they should be. For that reason there has been some dissatisfaction expressed by farmers, but, generally speaking, electrification of farms in that country has established itself on a firm basis. Other countries in which electrification along these lines is being promoted are Finland, Switzerland, New Zealand, and France, while several other countries are attacking the problem.

In several instances the countries that are being electrified are not highly industrialized and any expansion in the use of electricity must come through a broader distribution of electric service rather than through an increased employment of electric power within the urban districts.

A model electrical farm, to encourage the use of electricity in agriculture, is being established near Stockholm, Sweden, and demonstrations of electrically operated plows, harrows, harvesters, threshing machines, churns, separators, etc., will be given.

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Changes of advertising copy should reach this office by the 15th of the month for the issue of the following month.

Coming Convention Activities

SPRING CONVENTION

Prospects for a splendid convention at Pittsburgh April 24-26, indicate a program that will be very attractive to operating engineers. The Protective Devices Committee has furnished the keynote papers for the meeting and has assembled a splendid group of papers which will be presented at three sessions. The other two technical sessions will contain papers of general interest, one or two papers on the electric furnace and papers on the application of radio to interstation communication and to multiple street lighting control are expected to be available.

As tentatively arranged, the program calls for a session on the afternoon and evening of the 24th and one on the morning of the 25th at which papers dealing with grounding, protection, reactors, relays and grounded versus undergrounded neutral will be presented. On the afternoon of the 25th the members will be the guests of the Westinghouse Electric & Manufacturing Company and will visit the East Pittsburgh works and the research laboratory.

On the 26th two other technical sessions will be held and a dinner dance is contemplated for the evening of that day. It is expected that the evening session on the 25th will attract a large attendance from engineers in the Pittsburgh district who will be unable to attend the day sessions because of press of business.

The local committee in Pittsburgh in cooperation with the meetings and papers committee is working hard to make this one of the best national conventions ever held by the Institute both in its technical and social features. The Pittsburgh district affords opportunity for many interesting visits to engineering works and a large attendance from every section of the country is anticipated.

ANNUAL CONVENTION

Plans are well under way for the June Convention which will be held at Swampscott, Mass., June 25-29. A feature of the convention will be a lecture by Captain R. R. Belknap, U. S. N., on the "North Sea Mine Barrage." Captain Belknap will illustrate the lecture and bring out the electrical features associated with the war job of adequately placing mines in the North Sea during the war.

Also the research committee will present three or four notable papers on research which will make public the major research accomplishments of the year. The improvement in the quality of radio broadcasting should prove an interesting topic for several papers to discuss and in addition the educational committee hopes to present a notable paper or two on educational topics.

Work is well under way to develop a group of papers dealing with railroad electrification where it is hoped to bring out the viewpoint of railroad executives on this topic. Golf, tennis and other social features will be available to the delegates and the committees in charge of the convention anticipate a large attendance.

PACIFIC COAST CONVENTION

The Pacific Coast Convention Committee at its last meeting confirmed the tentative decision to hold the convention at Del Monte, Cal., September 25-28. It was also decided to hold three technical sessions at which nine papers will be presented, each representing an outstanding problem now facing the industry. Seven of the subjects have been announced as follows:

"Mechanical and Electrical Construction of Modern Power Transmission Lines," "Waterwheel Construction, Operating and Governing," "Experience of Manufacturing and Operating Engineers with Oil Switches," "Practise and Theory in High-Voltage Operation," "Operation of Group Power Sources with the Transformer Tertiary Winding in Operation," "Frequency Problems Arising with Extension of 60-Cycle Practise and Direct Current Parallel Operation of 45-Cycle and 60-Cycle Power Groups," "Radio Communication over Power Transmission Networks."

The ceremony of presenting the Edison Medal to Dr. R. A. Millikan will take place on the evening of September 26, and on the evening of September 27 a banquet will be held. The afternoons during the convention will be devoted to recreation in the historic neighborhood of Del Monte and Monterey, and on the afternoon of September 28 a special train will leave for Hetch Hetchy, in the Yosemite Valley, where members and guests will be shown the Moccasin Creek hydroelectric development and all the features of this water project of the city of San Francisco, which is designed to conserve water in the high Sierras and convey it 180 miles to San Francisco, developing 150,000 h. p. as a by-product.

Every effort is being made to make this the most interesting Institute convention ever held in the West.

The Midwinter Convention of the American Institute of Electrical Engineers has established itself as an occasion for interpreting and presenting to the electrical fraternity new discoveries and accomplishments in the theoretical aspects of electrical engineering. * * * * * Conventions such as this which serve to interpret, to apply and to record technical advances in the art, and which strive to stimulate research through rendering public homage to the specialists, are valuable to the electrical industry in even greater degree than those which exist for social purposes or for discussing commercial or engineering practises. All who attended the Midwinter Convention must necessarily have been stimulated and keyed to a higher pitch through meeting the leading specialists in the industry and hearing them describe the technical aspects in their fields.—*Electrical World.*

The Eleventh Midwinter Convention

The constantly increasing importance and popularity of the Institute Midwinter Conventions in New York was emphasized by the results of the eleventh annual Midwinter Convention held in the Institute headquarters, New York, February 14-17. This convention easily surpassed all its predecessors in points of attendance, variety and character of papers presented and novelty and scope of its entertainment features. The registered attendance of members and guests totaled about 1200 and the attendance at the technical sessions was so large that it was found necessary to transfer several sessions from the fifth floor assembly rooms for which they were scheduled, to the main auditorium.

The conduct of the meetings was planned with more than usual detail to take care of a rather crowded program, and the arrangements elicited much favorable comment. An estimate of the time required to present each paper was made, and each author confined his presentation to the allotted time. The papers were presented at the beginning of each session in nearly all cases, thus leaving a definite amount of time which could be devoted to discussions.

Among the features of outstanding interest at the Convention which attracted special attention were the joint session with the Chicago Section by means of telephone connections and loud speakers, the description of the machine switching telephone system which is being installed in New York and other large cities, and the smoker on Thursday evening at which the pallophotophone, an instrument which photographs and reproduces the human voice, was described and demonstrated.

Opening Session

WEDNESDAY AFTERNOON

The convention was formally opened by President Jewett who called the first session to order Wednesday afternoon at 2.30 o'clock. After a few words of welcome Pres. Jewett disclaimed any intention of prolonging an already crowded program by making a formal address, and introduced Mr. E. B. Meyer, chairman of the Transmission and Distribution Committee, who presided during the rest of the session. The following papers were then abstracted by their authors:

Report of Transmission and Distribution Committee, E. B. Meyer, Chairman. *Apparent Dielectric Strength of Cables*, by R. J. Wiseman. *Short-Circuit Currents in Networks*, by O. R. Schurig. *Qualitative Anlaysis of Transmission Lines*, by H. Goodwin, Jr. *The Heavisidion*, by Vladimir Karapetoff. *Cable Testing and Maintenance*, by H. S. Phelps and E. D. Tanzer.

These papers were discussed by R. D. Evans, J. L. R. Hayden, D. W. Roper, Edith Clark, John B. Whitehead, V. Karapetoff, C. P. Steinmetz, E. W. Davis, R. E. Doherty, G. M. Armbrust, C. L. Fortescue, S. J. Rosch, H. L. Wallau, G. B. Shanklin and W. N. Eddy, followed by closures by the authors.

New York-Chicago Joint Session

WEDNESDAY EVENING

President Jewett called the joint New York-Chicago Meeting to order Wednesday evening. This session was one of unusual interest, being the first meeting ever held in which two audiences 1000 miles apart were connected by means of two-way long-distance telephones with loud speaking instruments. All of the addresses, papers and discussions were also broadcasted. The significance of the meeting was well brought out in the opening remarks of President Jewett who said:

To you, members of the American Institute of Electrical Engineers, and to you, our guests assembled together in New York and Chicago, I wish in opening this first evening meeting of our Midwinter Convention especially to call your attention to the unique significance of the occasion which brings us together and of the epoch in engineering history which it marks, not only in electrical development but in the conduct of human affairs as well.

For the first time in the history of the world, groups of men and women, separated by hundreds of miles, are gathered together in a common meeting under a single presiding officer to listen to papers presented in cities separated by half the span of a continent, and to take part in the discussion of these papers with an ease characteristic of discussions in small and intimate gatherings. At the same time unnumbered thousands in their homes are auditors of our deliberations through radio broadcasting.

Who can picture the limits of the effect and influence which will flow from the developments of electrical science and electrical engineering which have made this night possible. In truth, we are participants in an historical event, and our children, nay even many of us, may see the agency we here use employed with mighty effect in controlling our collective relations in state and nation. Someone has said that the greatest political engine ever devised was the colonial town meeting where every question of importance was debated and discussed in an open forum of all the citizens. Be that as it may, we are well aware that our best government today is found in those small political units where the town meeting in some form is feasible and still persists. It is only when we come to the larger units of city, state and nation that the limitations on common discussion of vital matters, which are imposed by sheer physical size, evidence themselves in cumbersome and inadequate substitutes for personal discussion and oftimes in unsatisfactory results.

May it not be that in this two-way working telephone with its sensitive transmitters and loud speaking receivers we have the instrumentality for insuring a simpler and better ordering of our affairs—an instrumentality which will enable us to derive many of the benefits of the town meeting in the greater concerns of our national life. The mechanism which we are here using is one adapted to permit many speakers in many distant audiences to be heard by all who care to listen and take part in a common discussion. In voicing the opinion that this mechanism is destined profoundly to affect our political and economic machinery, I intend to convey no thought or picture of a pure democracy but only of a representative form of government in which all questions that would be helped by oral discussion can be so discussed without restraint from the physical limitations of the human voice or of distance. They might be discussions between widely separated groups on some matter of common concern or between a designated representative and his constituents, or in any of the thousand and one ways in which human beings better their condition by oral discussion.

In the hands of the members of this Institute the telephone has been developed from the first crude concept of Alexander Graham Bell's great contribution to knowledge and great gift to mankind, into a machine of incalculable influence in human affairs. The successful realization of a dream, a hope and an aspiration dating back to the pioneer days of Bell himself, namely, the production of a loud speaking telephone which would reproduce the human voice faithfully but in stentorian tones and in many places simultaneously has now been accomplished. In the solemn exercises attendant upon the burial of the Unknown Soldier at Arlington on Armistice Day a year ago, we had the curtains of the future drawn partially aside and saw vast audiences in New York and San Francisco commingled, as it were, with those who listened on the banks of the Potomac, but those exercises and all subsequent exercises and demonstrations have been in the nature of one-way transmission; that is, they have been arrangements in which the speakers were at one place and audience at one or more other places, or they have been arrangements where a single audience listened to speakers in different places. Tonight, for the first time, we are witnessing and making use of the next step in the development by employing an arrangement which enables many speakers and many audiences in many places to meet as one body.

From the arrangement at Arlington to that of tonight may seem as a logical next step. So it is for those who have the imagination to picture the future, but so too was the concept of a loud speaking telephone a simple logical next step to anyone who had witnessed the operation of an ordinary telephone. In both cases the next step easily logical in the imagination has been technically difficult in reality. It is neither my purpose nor my place as the presiding officer to trench upon the papers and discussion intended to describe and exemplify this new instrumentality. Before proceeding to the more formal part of our program, however, I wish merely to call your attention to the fact that we lack only direct distant vision to make this joint meeting one in very fact save only for the element of the personal proximity of those in attendance, and who among us is hardy enough to believe that this last limitation may not be removed within the lifetime of many of those now here. Fundamental and applied research are opening new doors daily in bewildering succession. When they open that last door which now prevents man from exercising at a distance all of his powers of personal intimate communication we will have another noteworthy meeting of this Institute.

Tonight, however, we must be content with full powers of speech and hearing but with partially defective vision. So it comes about that you, Mr. Schuchardt, our Vice President in Chicago, and you, Mr. Rhodes, my Vice-chairman, are each in a unique position, a position in which one of you is acting in place of the President at a meeting where the President himself is in attendance in his official capacity, and the other is acting similarly for the President in his capacity as presiding officer. Some day this may not

be necessary, but for the moment we are really acting as the eyes of this great joint meeting and are transferring as best we can the functions of distant vision by means of human speech.

The first paper presented entitled *Public Address Systems*, by I. W. Green and J. P. Maxfield was read by Mr. Green in New York. *The Use of Public Address Systems with Telephone Lines*, by W. H. Martin and A. B. Clark, was read by Mr. Martin. These papers were discussed by J. J. Carty and E. B. Craft (New York) and R. F. Schuchardt and B. E. Sunny (Chicago).

President Jewett next introduced Mr. William B. Potter who delivered an address on *Observations on Electric Railway Practise*, profusely illustrated by lantern slides which were shown simultaneously in New York and Chicago. Mr. Potter's lecture was discussed by A. L. Le Blanc, member of the A. I. E. E. and Societe Francaise des Electricians, Engineer of Compagnie Francaise Thomson-Houston, Paris, also speaking for Mr. Daviol, Electrical Engineer of the Paris-Orleans Railway of France.

Parallel Telephone and Miscellaneous Sessions

Thursday Morning

One of the parallel sessions on Thursday morning was under the auspices of the Telephony and Telegraphy Committee and President Jewett, after opening the meeting turned it over to O. B. Blackwell, chairman of that committee, who presided. Three papers were presented by the authors as follows:

Diaphragmless Microphone, for Radio Broadcasting, by Phillips Thomas, *Telephone Transmission Over Long Cables*, by A. B. Clark, and *Theory of Electric Filter Circuits*, by L. J. Peters.

In connection with Mr. Thomas's paper, J. E. Aiken gave a demonstration of the apparatus described in the paper.

Discussions followed by R. L. Jones, James J. Pilliod, J. B. Taylor and G. D. Robinson, with closure by Phillips Thomas.

The other parallel session on Thursday morning, after being called to order by President Jewett, was turned over to Mr. L. W. W. Morrow, Vice-Chairman of the Meetings and Papers Committee, who presided during this session. The following papers were all read by their authors with the exception of the paper by W. V. Lyon, which was ready by A. E. Kennelly. The papers were as follows: *Automatic Train Control Problems*, by E. J. Blake; *Application and Economics of Automatic Railway Substations*, by L. D. Bale; *Single-Phase Regeneration for Series Commutator Motors*, by L. J. Hibbard; *The Blondelion*, by Vladimir Karapetoff; *Transient in Electrical Machinery*, by W. V. Lyon, and *1922 Developments in Autovalve Lightning Arresters*, by A. L. Atherton.

Discussions followed by D. W. Roper, V. Karapetoff, Frank J. Sprague, Azel Ames, J. M. Lamberton, C. P. Steinmetz, E. J. Blake, L. D. Bale, A. L. Atherton, Joseph Slepian and R. F. Franklin.

Telephone and Telegraph Session

Thursday Morning

This session was called to order at 2.30 p. m. by Mr. O. B. Blackwell, Chairman of the Telephone and Telegraph Committee and after preliminary remarks he called for the presentation of the paper *Machine Switching Telephone System for Large Metropolitan Areas*. The paper was presented by Mr. Morehouse and the discussion which followed was by F. B. Jewett, Bancroft Gherardi, L. D. Bale, F. J. Chesterman, E. B. Craft and H. P. Charlesworth. The next paper *Wind Shielding Between Conductors*, was presented by the author, F. J. Howe and discussed by F. L. Rhodes, E. C. Keenan and K. L. Wilkinson. The last paper of the session entitled *The Wave Antenna*, by Harold H. Beverage, Chester W. Rice, and Edward W. Kellogg, was presented by Mr. Kellogg and discussed by O. B. Blackwell.

Electrophysics Session

Friday Morning

Mr. F. W. Peek, Jr., Chairman of the Electrophysics Committee presided at this session and after some remarks by President Jewett, called for the presentation of the following papers: *Dissymmetrical Electrical Networks*, by A. E. Kennelly; *Physical Interpretation of Complex Angles and Their Functions*, by A. Boyajian; *Radiation from Transmission Lines*, by Charles Manneback; *New Equation for Static Characteristics of Electrical Arcs*, by W. B. Nottingham; *Electromagnetic Forces; A Search for More Rational Fundamentals; A Proposed Revision of the Laws*, by Carl Hering; *Permeability*, by T. Spooner.

These papers were all presented by their authors with the exception of the paper by Chas. Manneback, which was abstracted by F. S. Dellenbaugh. An extensive discussion ensued, which was participated in by F. S. Dellenbaugh, A. E. Kennelly, L. E. Widmark, V. Karapetoff, Joseph Slepian, C. O. Mailloux, J. H. Morecroft, John Mills, John B. Taylor, Edward L. Bowles, Guerney H. Cole, A. Boyajian, Carl Hering and T. Spooner.

Instruments and Measurements Session

Friday Afternoon

The final technical session of the convention was called to order by Mr. John Mills, in the absence of President Jewett, and after some brief remarks Mr. Geo. A. Sawin, Chairman of the Instruments and Measurements Committee took the chair. The following papers were then abstracted by their authors:

Application and Limitation of Thermocouples for Measuring Temperature, by I. B. Smith; *Measurement of Power in Polyphase Circuits*, by C. Fortescue; *Kilovolt-Ampere Demand Measurement*, by H. C. Fryer; *Expansion of Oscillography by Portable Instrument*, by J. W. Legg; *Measurement of Transients*, by F. Terman; *Balance Methods in A-C. Measurement*, by P. A. Borden.

The discussion which followed was by R. D. Evans, J. R. Craighead, P. A. Borden, E. A. Tanzer, E. E. F. Creighton, C. L. Fortescue, G. H. Cole, V. Karapetoff, E. P. Peck, H. L. Curtiss, I. M. Stein, E. D. Doyle, R. C. Fryer, J. W. Legg, F. E. Terman. Thus concluded the technical sessions of the convention.

Entertainments

McGraw-Hill Inspection Trip

On Thursday, February 15, several hundred members and guests of the convention visited the publishing plant of the McGraw-Hill Company, where a buffet luncheon was served, followed by an inspection trip through this company's large and well-equipped publishing plant. The visitors were transported from the headquarters of the Institute to the McGraw-Hill plant at 10th Ave. and 36th St., by means of busses. They assembled on the 12th floor, where after a brief address of welcome by a representative of the company, luncheon was served. The party was divided into different groups of about a dozen each, and each group was in charge of a guide who conducted it through every part of the plant, including the business, editorial and art department and through the mechanical department, which includes printing, binding and mailing. The visit was thoroughly enjoyed by all who attended and the visitors were brought back to the Engineering Societies Building just in time for the afternoon session.

Smoker

The Smoker held Thursday evening under the auspices of the New York Section of the A. I. E. E. proved to be one of the most enjoyable and appreciated innovations that has ever been introduced at the Midwinter Convention. There were 700 members and guests in attendance, which severely taxed the capacity of the fifth floor assembly rooms, where the meeting was held. The early part of the evening was devoted to a program of entertainment, after which light refreshments were served and the balance of the evening until well after midnight, was spent in informal social intercourse.

The evening's program opened with a moving picture of "Daily Events," which was followed by character songs by

Joseph McKenna. This was followed by a newly released moving picture entitled "Developments of Aviation," showing the progress of this science from the early days of the Wright brothers up to the present time. Addresses were then made by A. E. Waller, Secretary, and Calvert Townley, Chairman of the New York Section, after which the pallophotophone was described and demonstrated by Mr. C. A. Hoxie.

This instrument records on a moving film the light beams from a very small mirror, mounted so as to follow the movement of a diaphragm on which the sound falls. In reproducing the sound, the film is passed in front of a light beam which effects the light falling on a light-sensitive cell, which in turn varies the current to correspond with the original voice wave. The device seems destined to make the talking motion picture a reality. The purity of the voice reproduction is remarkable and it is free from the inherent characteristic defects of most mechanical contrivances for voice reproduction. To demonstrate this feature of purity Mr. Hoxie gave a short prepared speech from the adjoining room, once vocally and once reproduced on the pallophotophone. He asked the audience to guess which was vocal and which was reproduced and the raising of hands showed the audience about equally divided in their opinions.

Following this demonstration Mr. Jack Arnold gave monologues with many entertaining stories and Mr. Albert Baker gave amusing examples of ventriloquism. This concluded the formal program.

Dinner Dance

The convention closed Friday evening with the annual dinner-dance at the Hotel Astor. This function was attended by over 500 guests, which makes it the best attended dinner-dance in the history of the Institute.

Inspection Trips

Many small parties during the convention and on the Saturday following made visits of inspection to various plants and laboratories in and around New York City, which had courteously been opened to members and guests of the convention. Among the plants so visited were the Pennsylvania Machine Switching Station, the New York Telephone Company, the Bell System Research Laboratories, the American Telephone and Telegraph Broadcasting Station, Power Plants of the Interborough Rapid Transit Company, the New York Edison Co., the Power Station of the United Electric Light & Power Co., the Essex Power Station of the Public Service Electric Company and the Electrical Testing Laboratories. On Friday afternoon a number of the lady guests were entertained at the laboratories of *Good Housekeeping Magazine*, where tea was served.

Ethics of the Engineering Profession

A reprint of the Code of Principles of Professional Conduct, adopted by the A. I. E. E. in 1912, has recently been published and is available for free distribution upon application to the secretary of the Institute. This brings to mind the decided trend during the past few years toward the formulation and adoption of codes of ethics by numerous organizations in different fields of activity. Such codes have become important agencies in upholding high ideals in the constantly broadening social, economic and industrial relations of the various groups concerned.

The engineering profession was slow to adopt such codes, because of the prevalence of the more general view that an adherence to the Golden Rule would meet all the requirements, without formulating specific applications to the engineering field. The broadening concept of the profession, due to its increasing contacts with the varied activities of life, gradually brought about a realization that a simple statement of desirable procedure in the more common relations of groups and individuals within the profession, would be very helpful, particularly to the younger engineers.

These views, stimulated by the presidential address of Dr. Schuyler S. Wheeler on "Engineering Honor" presented before the A. I. E. E. in 1906, led to the adoption of the Code by the A. I. E. E. in 1912. Ten years later, namely, in March 1922, the Board of Directors of the Institute adopted resolutions reaffirming adherence to the Code, which "had served its purpose effectively during the past ten years." At the same time the Directors adopted a resolution providing that "in addition to its function of formulating and administering a code, it shall be the duty of the Committee on Code of Principles of Professional Conduct to advise inquirers respecting questions of proper professional conduct, and to examine into and investigate any practise of any member of this Institute which may be regarded as prejudicial to the welfare of the Institute, the engineering profession, or of the community, and to report its actions and recommendations to the Board of Directors, which shall take such action thereon as it may deem proper." Acting under this resolution, the Institute's committee has investigated matters coming within the scope of the Code and concerning members of the Institute, and appropriate action was taken in each instance.

Since the adoption of the Code by the Institute in 1912, several other engineering societies have also adopted codes of conduct, including the national societies of civil and mechanical engineers; and these other societies have also established committees or other agencies for the administration and enforcement of such codes.

An interesting feature which is clearly brought out by a comparison of the more recently adopted codes with the original, is that viewed all together they form strong indorsement of the principle of standardization. Some of these codes were prepared independently, purely in response to the demand for briefer and simpler statements of the leading principles; but after these had passed through the hands of the many who assisted with criticisms, etc., and were brought out in their respective final forms, their resemblance to the Code of the Electrical Institute is striking. They not only cover practically the same subjects and are expressed in substantially the same language, but their authors have seen fit, after much consideration, to make their general structure, that is, the division of subjects and the arrangement, follow very closely the A. I. E. E. Code of 1912.

Southern Virginia Section Organized

On January 22, 1923 the organization meeting of the Southern Virginia Section of the A. I. E. E. was held at Richmond, Va. The meeting was called to order by W. C. Bell and the following Executive Committee was elected: W. C. Bell, Chairman; H. C. Leonard, Secretary; C. H. Quinn, W. S. Rodman, L. W. Webb. By-laws were adopted and resolutions passed advocating cooperation with various other engineering societies in the State in the formation of a Technical Council. An informal discussion of plans for the ensuing year followed.

Scholarship in Electrical Engineering at Columbia University

The governing bodies of Columbia University have placed at the disposal of the American Institute of Electrical Engineers a scholarship in Electrical Engineering in the Schools of Mines, Engineering and Chemistry of Columbia University. The scholarship pays $350 toward the annual tuition fees which vary from $340 to $360, according to the details of the course selected. Reappointment of the student to the scholarship for the completion of his course is conditioned upon the maintenance of a good standing in his work.

To be eligible for the scholarship, the candidate recommended will have to meet the regular admission requirements, in regard to which full information will be sent without charge upon appli-

cation to the Secretary of the University or to the Secretary of the Institute.

In a letter addressed to the Secretary of the Institute, an applicant for this scholarship should set forth his qualifications (age, place of birth, education, reference to any other activities, such as athletics or working way through college, references and photograph). A committee composed of Messrs. Francis Blossom, F. B. Jewett and W. I. Slichter will consider the applications and will notify the authorities of Columbia University of their selection of a candidate. The last day for the filing of applications for the year 1923-24 will be June 1, 1923.

The course at the Columbia School of Mines, Engineering and Chemistry, is 3 years in length and is on a graduate basis. A candidate for admission must have had something of a general education, including considerable work in mathematics, physics and chemistry. Three years of preparatory work in a good college or scientific school should be sufficient, if special attention has been given to the three preparatory subjects mentioned. A college graduate, with a Bachelor of Science degree in engineering, can generally qualify to advantage. The candidate is admitted on the basis of his previous collegiate record, and without undergoing special examinations. Other qualifications being equal, members of Student Branches of the A. I. E. E. will be given preference.

The purpose of this advanced course is to produce a high type of engineer, trained in the humanities as well as in the fundamentals of his profession. It is hoped that members will show a keen interest in this scholarship, which will insure the choice of a candidate of the highest qualifications.

Scholarship in Electrical Engineering at Stanford University

Through the generous gift of Mr. Cyril F. Elwell, there is available in the Electrical Engineering Department of Stanford University for the academic year 1923-24 a scholarship carrying a stipend of $500. This scholarship is designated by the authorities of the University the "Elwell Scholarship."

The purpose of the scholarship is to assist some young man of intellectual promise, but of limited means, in undertaking a year of graduate study in the Electrical Engineering Department of Stanford University. However, it is expected that the holder of the Elwell Scholarship shall be supplied with sufficient funds so that, with the assistance of the $500 stipend attached to the scholarship, he may be supported in a fair degree of comfort without being compelled, during such times as the University is in session, to do remunerative work to add to his income.

It is required that an applicant shall have gained, at least, the degree of Bachelor of Science in Electrical Engineering or its equivalent. However, applications will be considered from those who have received the degree of Bachelor of Science, or its equivalent, in Mechanical, Civil, Mining, or Chemical Engineering. For both classes of applicants, this year's work normally leads to the degree of Engineer in Electrical Engineering.

Each application should set forth as far as may be practicable the plans of the applicant relating to his proposed program of studies, and also in relation to his probable choice of work following the year at Stanford. The applicant should request several persons who are competent to judge of his character and of his intellectual ability to write directly to the university in support of his application. An essential part of every application is a transcript of all the grades made by the applicant in his previous college courses. This transcript must be an original document issued and certified by the registrar (or corresponding officer) of the college concerned. Address all correspondence to Professor Harris J. Ryan, Executive, Electrical Engineering Department, Stanford University, California.

Future Section Meetings

Baltimore.—March 18, 1923. Subject: "Wired Wireless." Speaker: Mr. R. D. Duncan, Jr.

April 20, 1923. Subject: "Insulator Design and Manufacture." Speaker: Mr. K. A. Hawley.

Boston.—March 13, 1923. Subject: "Design of Transformers and Other Features of the Queenston Plant at Niagara Falls," by Mr. M. E. Skinner and "The Trend of Power Transformer Development," by Mr. M. O. Troy.

March 30, 1923. Joint meeting with the New England Section of the Illuminating Engineering Society. Subject: "The History of Artificial Illumination from the Dawn of Civilization to the Present Time." Speaker: Dr. M. Luckiesh.

April 16, 1923. Subject: "The Panama Canal—Operation, Traffic and Future," by Brig.-Gen. Chester Harding, U. S. A., retired.

Chicago.—March 19, 1923. Joint meeting of the Western Society of Engineers. Subject: "Industrial Research." Speaker: Mr. C. E. Skinner.

Cleveland.—March 22, 1923. Subject: "Motors, Bearings, Brakes, Clutches, Control." Speaker: Mr. MacCutcheon.

April 19, 1923. Subject: "Manufacture of Copper Wire and Cable." Speaker: Mr. C. F. Hood.

Detroit-Ann Arbor.—March 16, 1923. Associate Technical Society Meeting, sponsored by A. I. E. E.

April 13, 1923. Speaker to be announced.

Minneapolis.—March 16, 1923. Subject: "National and International Standardization." Speaker: Mr. C. E. Skinner.

April 2, 1923. Subject: "Carrier Current Telephony." Speaker: Mr. H. A. Affel.

Philadelphia.—March 12, 1923. Subject: "Recent Developments in Thermionic Tubes." Speaker: Mr. Saul Dushman.

April 9, 1923. Subject: "Arrester Protection." Speaker: Major Malcolm MacLaren.

Pittsfield.—March 15, 1923. Subject: "Vacuum Tubes and Their Application." Speaker: Dr. Irving Langmuir.

March 29, 1923. Subject to be announced. Speaker: Mr. G. Faccioli.

Rochester.—March 23, 1923. Subject: "Relay Protection." Speaker: Mr. Hunting.

April 27, 1923. Subject: "Economics of Railway Electrification." Speaker to be announced.

Seattle.—March 21, 1923. Subject: "A Radio Stunt Night." Speaker: Mr. J. D. Ross.

March 23, 1923. Subject: "Power Factor Correction." Speaker: Mr. F. F. Ambuhl.

April 6, 1923. Joint meeting with the Engineering Institute of Canada at Hamilton. Speaker not chosen.

April 18, 1923. Subject: "The Columbia Basin Project." Speaker: Mr. Willis T. Batcheller.

April 20, 1923. Subject and speaker not chosen.

Washington, D. C.—March 13, 1923. Subject: "Electrical Equipment on Automotive Vehicles." Speaker: Mr. J. H. Hunt.

Worcester.—March 15, 1923. Subject: "The Development of Illumination." Speaker: Mr. W. D'A. Ryan.

April 12, 1923. Subject and speaker to be announced later.

Bombay Association of Institution of Engineers Holds First Annual Meeting

The First Annual Meeting of the Bombay Association of the Institution of Engineers (India) was held on November 28 and 29 at Bombay. Two papers were presented: "The Advantages and Disadvantages of the Intercepting Trap in the Drainage System in Bombay," by K. B. Dadyburjor, and "Pulverized Coal as a Fuel," by T. S. Dawson. There were two inspection trips, and a dinner on the last evening at the Taj Mahal Palace Hotel.

Societe des Ingenieurs Civils de France

Some months ago the United Engineering Society adopted a resolution offering the facilities of meeting rooms in the Engineering Societies Building, New York, to the members of the American Section of the French Society of Civil Engineers. The invitation was accepted and a few meetings have been held.

Recently the French society has returned this courtesy by extending to the American engineers in Paris the privilege of the use of the rooms of that society for such occasional meetings as may be held.

This exchange of courtesies will naturally tend to enhance the already cordial relations existing between the American and French engineering societies.

Annual Meeting Date of the Electric Power Club

The next annual meeting of the Electric Power Club will be held on June 11th to 14th, inclusive, at the Homestead, Hot Springs, Virginia, where this Association was organized in 1908.

It is expected that a considerable amount of important standardization of electric power apparatus will be effected at that meeting, because the new edition of the Electric Power Club Handbook will be published soon thereafter, and all the different sections of the club are working to accomplish as much as possible this Spring, in order to get their work into the new Handbook.

AMERICAN ENGINEERING COUNCIL

ENGINEERS AS PUBLIC LEADERS

The colleges of the country are urged to "point engineers toward leadership in public affairs" in a report submitted to the Federated American Engineering Societies by its Committee on Industrial Ideals, of which Prof. Joseph W. Roe, head of the Department of Industrial Engineering at New York University, is chairman.

The report stresses the need of the engineer in public life, asserting that he must aid in removing the difficulties of the material world which he has created. Carrying out the idea expressed by Edwin Ludlow, past-president of the American Institute of Mining and Metallurgical Engineers, that "this is an engineer's country but a lawyer's government," the report continues:

"For a century, engineers have directed their energy toward the utilization of the physical forces and the materials of nature. The developments which they have brought about have created an epoch in human history.

"While these developments have been of inestimable benefit, and modern society could not exist without them, they have introduced many public problems and social readjustments, so closely related to the engineer's activities, that it is increasingly evident he must assume an active part in their solution.

"Recognizing this growing need, the engineers of the country formed the Federated American Engineering Societies, primarily to place their knowledge and training at the public service on all public matters affecting engineering, or affected by it.

"Engineering education, reflecting closely the attitude of engineers heretofore, has confined its work almost exclusively to scientific and technical training, giving little, if any attention to the social and human aspects of engineering enterprises.

"The Federated American Engineering Societies, therefore, speaking for the engineering profession, urges upon engineering colleges an increased attention to the social aspects of engineering activities, and a broadening of their technical training, in every way possible, to develop in engineering students the spirit of, and a capacity for, active leadership, not only in industry but in public affairs."

The other members of the committee, whose report has been adopted by the governing body of the Federation, are: Mortimer E. Cooley, Dean of the Engineering Schools of the University of Michigan and successor of Herbert Hoover as president of the Federation; Prof. C. F. Scott of Yale University and J. C. Ralston of Spokane, Wash.

Dean Cooley, in making public the report, declared that the American engineering profession "was on the eve of great developments, not so much in the engineering as in the social sense." The engineer, he added, was going to take the place in the world to which he was entitled. It was probable, he said, that the Federation would soon undertake another national public service ranking in importance with the Report of Waste in Industry and the Report on the Two-Shift Day.

NATIONAL RESEARCH COUNCIL

APPARATUS AND SUPPLIES FOR RESEARCH

Is an instrument for my present need available or must I design one? Where may a specified type of apparatus be obtained? Where may plans for laboratory construction and ideas about special equipment be had? What are the best sources of certain chemical or other supplies for research? These are samples of recurrent questions from the research laboratory.

This is obviously an era of research accompanied by phenomenally successful application of results to engineering and other types of industrial need. The hundreds of research laboratories which now exist in this country are making heavy demand on manufacturers and distributors of research equipment and supplies.

With the purpose of helping to meet the growing demand for information the Research Information Service of the National Research Council has assembled catalogues and lists of research appliances issued by makers and dealers. Publications of nearly 500 domestic firms and nearly 200 foreign firms are now on file. They have been classified for effective use and a subject catalogue of apparatus has been prepared. The Serviceh as also an up-to-date list of manufacturers and distributors of research chemicals.

If the Service cannot supply just the information that you desire it ordinarily can at least put you in touch with some such useful source of information as manufacturer, dealer or designer.

Electrical engineers and investigators who desire assistance in locating special instruments, apparatus or supplies for use in their laboratories are invited to avail themselves of the resources of this organization.

The appropriate address for inquiries is Information Service, National Research Council, Washington, D. C.

English Metallurgist Lectures at American Colleges

Dr. Walter Rosenhain, head of the metallurgical department of the National Physical Laboratory at Teddington, England, has arrived in America to address universities, engineering societies and other organizations, it is announced by the Federated American Engineering Societies.

On February 19, Dr. Rosenhain spoke before the Metals Division of the American Institute of Mining and Metallurgical Engineers at 4 p. m. in the Engineering Societies Building, 29 West 39th Street. His subject was "Solid Solutions."

During February Dr. Rosenhain visited Lehigh University and Franklin Institute at Philadelphia. He spoke at Columbia University on February 23, and on February 26, 27 and 28 he was at Yale. In March he will be heard by the Production Club of Waterbury, Conn.

Other places in Dr. Rosenhain's itinerary include: Massachusetts Institute of Technology, March 5, 6 and 7; Corning, N. Y.,

March 10; Case School of Applied Science, Cleveland, March 12 and 13; University of Michigan, March 14, 15 and 16; Detroit, March 17, 18 and 19, addressing the American Society for Steel Treating on the 19th; University of Illinois, March 20, 21 and 22; Chicago, March 23 and 24; Toledo, O., March 26; Dayton, O., Engineers' Club, March 27; Huntington, West Va., March 28; Charleston, West Va., March 29; Pittsburgh, March 30; Washington, D. C., April 1-5.

Dr. Rosenhain's New York address was delivered in connection with the annual meeting of the American Institute of Mining and Metallurgical Engineers.

Following are the subjects of the lectures delivered by Dr. Rosenhain: "Hardness and Hardening," "The Structure and Constitution of Alloys," "Strain and Fracture in Metals," "Aluminum Alloys," and "Metallurgical Research at the National Physical Laboratory, England."

Engineering Societies Library

The library is a cooperative activity of the American Institute of Electrical Engineers, the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers and the American Society of Mechanical Engineers. It is administered for these Founder Societies by the United Engineering Society, as a public reference library of engineering and the allied sciences. It contains 150,000 volumes and pamphlets and receives currently most of the important periodicals in its field. It is housed in the Engineering Societies Building, 29 West Thirty-ninth St., New York.

In order to place the resources of the Library at the disposal of those unable to visit it in person, the Library is prepared to furnish lists of references to engineering subjects, copies or translations of articles, and similar assistance. Charges sufficient to cover the cost of this work are made.

The Director of the Library will gladly give information concerning charges for the various kinds of service to those interested. In asking for information, letters should be made as definite as possible, so that the investigator may understand clearly what is desired.

The library is open from 9 a. m. to 10 p. m. on all week days except holidays throughout the year except during July and August when the hours are 9 a. m. to 6 p. m.

EXTRACTS FROM ANNUAL REPORT FOR 1922

During the past year the Engineering Societies Library has enjoyed a quiet growth along lines explained in previous reports and there has been no new departures of any considerable magnitude. The recataloging of the collection is steadily progressing and from the results obtained it is evident that previous estimates of the library contents were too large. Considerable duplication existed and much material has been found no longer worth preserving.

Estimates of the library collection on Dec. 31, 1922, show the following figures:

The income and expenses of the Library during 1922 were as follows:

Volumes	117,308
Pamphlets	32,419
Maps and Plans	1,576
Manuscript Bibliographies	3,904
Total	155,207

General Operation

Income, 1922

Appropriations:	
Founder Societies	$22,000.00
*United Engineering Society	306.05
National Electric Light Association	1,000.00
Carnegie Corporation	2,900.00
Endowment Fund	4,914.70
Total	$31,120.75

Expenses, 1922

Salaries	$19,631.58	
Books	1,349.94	
Binding	3,281.61	
Periodicals	2,602.28	
Supplies & Miscellaneous	1,373.43	
Equipment	732.58	
Insurance	842.56	29,813.98
Operating Surplus		$1,306.77
Operating deficit December 31, 1921	$60.63	
†Interest accrued on Endowment Fund 1921, charged off during 1922	1,246.14	1,306.77
Operating balance		$00.00

Recataloging

Income, 1922

Appropriations:		
Founder Societies		$10,000.00
Carnegie Corporation		7 100.00
Miscellaneous Receipts		275.75
Total		$17,375.75

Expenses, 1922

Salaries		$14,248.28
Operating surplus		$3,127.47
Operating deficit December 31, 1920	$1,950.49	
Operating deficit December 31, 1921	1,106.15	3,056.64
Operating balance		$70.83

Service Bureau

Amount Billed

Search Dept.		$9,411.81
Photoprint Dept.		5,421.19
Total		$14,833.00

Expenses, 1922

Salaries, Searchers	$7,990.66	
Salaries, Photographers	3,143.19	
Supplies, Search	719.08	
Supplies, Photographic	1,473.20	$13,326.13
Operating surplus		$1,506.87
Operating deficits, December 31, 1921		
Search Department	929.02	
Photoprint Department	17.16	
Accounts written off	417.53	1.363.71
Operating balance		$143.16

Condition of Accounts Receivable

Search Department	$1,906.28
Photoprint Department	258.35
	$2,164.63
Accounts written off	417.53
Net accounts receivable, December 31, 1922	$1,747.10
Accounts receivable, December 31, 1921	2,111.25

The complete annual report may be obtained by applying to the Director of the Library, Engineering Societies Building, 33 West 39th St., New York.

*To remove deficit caused by change of accounting from accrual to cash basis.

†Because of change from accrual to cash basis.

BOOK NOTICES, JANUARY 1-31, 1923.

Unless otherwise specified, books in this list have been presented by the publishers. The Society does not assume responsibility for any statements made; these are taken from the preface or the text of the book.

All the books listed may be consulted in the Engineering Societies Library.

Annuaire du Bureau des Longitudes. 1923.

By France: Bureau des Longitudes. Paris, Gauthier-Villars et Cie, [1922]. 860 pp., por., maps, tables, 6 x 4 in., paper. 6 fr. 5o.

This convenient reference book has appeared annually for 128 years. The volume for 1923, like its predecessors, covers a wide field of statistical information, astronomical, physical, geographical and social. Five star maps are included, and an extensive review of the climate of France.

Bibliographical History of Electricity and Magnetism.

By Paul Fleury Mottelay. Lond., Charles Griffin & Co., Phila., J. B. Lippincott Co., 1922. 673 pp., plate, por., 10 x 6 in., cloth.

(Gift of J. B. Lippincott Co.)

This work is the definitive edition of the author's "Chronological History of Magnetism, Electricity and the Telegraph," which had tentative publication (1891-1892) in the *Electrical World* and other journals. Since that publication it has undergone a thorough revision and a very large number of new references has been added.

The volume contains a series of references, arranged chronologically, to writings upon electrical science. A period of 4458 years is covered, from 2637 B. C., the earliest date when history notes anything resembling the application of the magnetic influence, to 1821, when Faraday discovered electromagnetism. Each entry gives a concise account of the work of an investigator, and a list of the authorities consulted by the author. The volume is a remarkable example of erudition and industry, which will be welcomed as a guide to the records of the earlier workers and writers.

The Dynamo, Its Theory, Design and Manufacture. Vol. 1.

By C. C. Hawkins. 6th edition. London & N. Y., Isaac Pitman & Sons, 1922. 615 pp., illus., diagrs., 9 x 6 in., cloth. $6.00.

A standard British text of comprehensive character, covering both direct and alternating-current generators. In this revision greater space is given to the treatment of the electromotive force of the dynamo by vectorial methods, the theory of armature winding has been reconsidered and expanded and greater prominence is given to drum armatures. A section on the oscillation of a mechanical system, a discussion of the compressive stress on the mica plates in high-speed commutators and the winding of shunt coils with two sizes of wire are among the new matters that have been added. The book has been largely rewritten and carefully revised.

Electrical Engineering Laboratory Experiments.

By C. W. Ricker & Carlton E. Tucker. 1st edition. N. Y. & Lond., McGraw-Hill Book Co., 1922. 310 pp., diagrs., 9 x 6 in., cloth. $2.25.

To make laboratory teaching effective, the student should be carefully supervised at the beginning of his course in order that he may learn as rapidly as possible the fundamentals of electrical testing and use them as tools for his more advanced work. He should then be assigned work that will require original thinking and be required to rely more or less upon his own resources.

In preparing this book the writers have kept these thoughts in mind. The text is intended to be flexible enough for adaptation to almost any course. It has grown out of extended experience in the Massachusetts Institute of Technology.

Elementary Internal Combustion Engines.

By J. W. Kershaw. 2d edition; Lond. & N. Y., Longmans, Green & Co., 1922. 211 pp., diagrams., 7 x 5 in., cloth. $1.75.

An elementary account of the construction and working of oil and gas engines and power-gas producers, intended as an introduction to more advanced books.

Experimental Electrical Engineering and Manual for Electrical Testing. Vol. 1.

By Vladimir Karapetoff. 3rd edition. N. Y., John Wiley & Sons; Lond., Chapman & Hall, 1922. 795 pp., illus., diagrs., 9 x 6 in., cloth. $6.00.

This textbook on the testing of electrical machinery is based on the course of instruction given by the author at Cornell University,but the selection of material has been modified by comparison with the courses in other colleges, so that the book presents a composite picture of what is actually taught in the electrical laboratories in this country.

This edition has been completely revised and reset. Volume one contains all elementary experiments and is sufficient for the needs of general students. Volume two contains advanced work needed by students of electrical engineering.

Internal-Combustion Engines.

By J. Okill. Lond., & N. Y., Isaac Pitman & Sons, [1922]. (Pitman's Common Commodities and Industries). 126 pp., illus., 7 x 5 in., cloth. $1.00.

A review of the development and construction of the various types of internal combustion engines, written to show how gas and oil engines stand as competitors to steam for all power purposes, and to discuss some of the power requirements that are beyond the scope of the steam engine.

Labor Turnover in Industry.

By Paul Frederick Brissenden & Emil Frankel. N. Y., Macmillan Co., 1922. 215 pp., tables, 9 x 6 in., cloth. $3.50.

The questions discussed in this work include the general extent of labor mobility; labor mobility in individual plants and in special groups within the work force, causes of turnover, seasonal influences, effects of length of service, responsibility for instability. The investigation is based on statistics collected for the United States Bureau of Labor Statistics, from over 260 establishments employing over 500,000 workers. The problem is treated primarily from the point of view of the individual establishment.

Machinery Foundations and Erection.

By Terrell Croft. 1st edition. N. Y. & Lond., McGraw-Hill Book Co., 1923. 691 pp., illus., diagrs., 8 x 6 in., cloth. $5.00.

Section one of this book considers the general requirements that foundations for machinery must meet. This statement of fundamentals is immediately followed by divisions treating of the design and properties of the different components of foundations, such as anchor-bolts, anchor-plates and anchors. Following these come instructions on the installation and reconstruction of foundations.

The divisions in the next group give specific information on the design and construction of foundations for certain types of machinery, including steam engines, and turbines, boilers, waterwheels, electrical machinery, hammers and planers. The concluding divisions explain methods for erecting machinery.

The book is written for practical men, and avoids the use of higher mathematics. Little has been written previously on the subject.

Oil Power.

By Sydney H. North. Lond., & N. Y., Isaac Pitman & Sons, 1922. (Pitman's Common Commodities and Industries). 122 pp., illus., tables, 7 x 5 in., cloth. $1.00.

A concise, yet comprehensive account of the use of oil for power production, which covers the subject in a general manner, without attempting great detail on its many aspects. Intended for engineers, shipowners and users of fuel. Gives special attention to the economic advantages of oil.

Vector Calculus, with Applications to Physics.

By James Byrnie Shaw. N. Y., D. Van Nostrand Co., 1922. 314 pp., 8 x 5 in., cloth. $3.50.

Embodies the author's lectures to graduate students. The attempt has been to give a text to the mathematical student on the one hand, in which every physical term beyond mere elementary terms is carefully defined. On the other hand for the physical student there is a large collection of examples and exercises which will show him the utility of the mathematical methods. The system adopted is algebraic.

United Engineering Society Extracts from Treasurer's Report for 1922

The following extracts are taken from the report of the Treasurer of the United Engineering Society, covering the calendar year 1922:

CASH STATEMENT, YEAR 1922

RECEIPTS

Cash on hand January 1, 1922		$14,219.35
from Founders & Associates	$138,294.27	
" Societies not in Building	17,811.17	
" Various Accounts	41,994.08	
" L. S. B. Photo Dept.	5,515.06	
" L. S. B. Search Dept.	9,274.28	212,888.86
		$227,108.21

PAYMENTS

For Operating Payroll	$46,919.31	
" Operating Expenses	37,225.22	
" Equip. Repairs & Alterations	10,195.56	
" Misc. Incl. Taxes	53,144.50	
" Library	56,868.73	204,353.32
Cash on hand January 1, 1923		$22,754.89

Distributed as follows:

Operating Cash	$13,250.01
General Reserve Fund, Uninvested Principal	2,500.00
Library Endowment Fund Uninvested Principal	313.65
Engineering Foundation Fund Uninvested Principal	446.33
Depreciation & Renewal Fund Uninvested Principal	5,920.84
John Fritz Medal Fund, Income	324.06
	$22,754.89

SUMMARY OF FUNDS, DECEMBER 31, 1922

Depreciation & Renewal Fund	$133,233.69
General Reserve Fund	10,000.00
Library Endowment Fund	93,357.40
Engineering Foundation Fund	502,074.80
John Fritz Medal Fund	3,500.00
Total	$742,165.89

ASSETS AND LIABILITIES

December 31, 1922

ASSETS

Property		*$1,959,140.67
Land	$540,000.00	
Building	1,361,969.51	
Equipment	33,171.16	
Founders' Preliminary Expenses	24,000.00	
Investments Engineering Foundation		502,074.80
Library		93,357.40
Depreciation and Renewal		133,233.69
General Reserve		10,000.00
Operating Cash	13,350.01	
Library Petty Cash	50.00	
Accounts Receivable	3,869.65	17,269.66
		$2,715,076.22

LIABILITIES

Founders Equity in Property		$1,959,140.67
Engineering Foundation Fund		502,074.80
Library Endowment Fund		93,357.40
Depreciation & Renewal Fund		133,233.69
General Reserve Fund		10,000.00
Deferred Credits—unexpended balance in International Dinner Fund	$54.89	
Library Income for year 1923	200.00	254.89
Balance in Activity Accounts		17,014.77
		$2,715,076.22

*Total of Actual Expenditures.

PERSONAL MENTION

C. H. MATTHEWS is now connected with the Hudson Coal Co., Scranton, Pa. His former work was with M. A. Hanna & Co., Cleveland, O.

J. E. BROKEMYR has resigned from the Utah Power & Light Company to become associated with the Drafting Department, Stone & Webster, Inc., Boston, Mass.

H. W. BROWN has accepted a position with the Postum Cereal Co., Battle Creek, Mich. He was formerly with the American Agricultural Chemical Co., Detroit, Mich.

N. B. AMBLER has resigned from the employ of the Toronto Power Company, Ltd., Niagara Falls, Ont., to accept a position with McClellan & Junkersfeld, 45 William St., New York City.

H. S. RUSSELL, until recently with the St. Joseph Railway, Light, Heat & Power Company, St. Joseph, Mo., has accepted a position with the Virginian Power Company, Charleston, W. Va.

E. A. GRAHAM, formerly connected with the Electric Bond & Share Company, 71 Broadway, New York City, has accepted a position with the Compania Electrica de Cienfuegos, Cienfuegos, Cuba.

J. L. STANNARD has been appointed Chief Engineer of the Lake Cushman Power Project for the city of Tacoma, Wash., resigning from his present position with Grant Smith & Co., San Francisco, Cal.

WALLACE W. BRIGGS has severed his connection with the Westinghouse Lamp Co., New York City, to become Vice-President of the United States Gasoline Mfg. Co., 165 Broadway, New York City.

H. TABOSSI has accepted a position with the General Electric Company in South America as commercial engineer, having held a similar position with the British Thomson-Houston Co., Ltd., in Rugby, England.

CHASE DONALDSON, formerly appraisal engineer with the American Gas & Electric Company, has resigned and is now an investigator for security issues with Hayden, Stone & Company, 25 Broad St., New York City.

V. Y. DAVOUD is now with the Engineering Department of the Electric Bond and Share Company, 71 Broadway, New York City. His former position was with the Utah Power & Light Company, Salt Lake City, Utah.

O. E. BURLEEN has accepted the western management of the Graham & Norton Company, 126-11th Ave., New York City, with headquarters in Chicago, Ill. He was formerly with the Elevator Supply Company, St. Louis, Mo.

ANDREW J. McGREGOR has become associated with the McGraw-Hill Company as Markets and Research Engineer on *Power*. He was formerly with Roy D. Lillibridge, Inc., New York City as Technical Advertising Engineer.

G. B. NICHOLS has opened an office at 300 Madison Ave., New York City, as Designing and Consluting Engineer, specializing in public buildings. He has been for ten years Chief Engineer in the Department of Architecture, New York State.

JOHN O. MONTIGNANI, formerly Engineer of Electric Distribution and Division Superintendent with the Rochester Gas & Electric Corporation, is now employed with the Westchester Lighting Co., Mt. Vernon, N. Y., as Assistant Electrical Engineer.

JOHN M. BOND has resigned as Head of the Car Equipment Test Department of the Interborough Rapid Transit and New York Railways Companies, New York, to accept a position as Sales Engineer for the National Carbon Company, Carbon Products Division, Chicago, Ill.

W. G. WATSON, Managing Director of W. G. Watson & Co., Ltd., Electrical Engineers and Merchants, Sydney, Australia, will visit America on business, arriving by the "Niagara" at Vancouver on March 24th. Letters should be addressed to him c/o

Hotpoint Division of the Edison Electric Applicance Co., Inc., Los Angeles, Cal., and after March 24th, c/o G. J. Mitchell Corporation, 3240 W. Lake St., Chicago, Ill.

J. Rowland Bibbins has recently resigned as Manager, Transportation Department, United States Chamber of Commerce, for consulting engineering practise in transportation and its related economic and civic problems, During his two years in Washington, Mr. Bibbins devoted special study to the whole group of transport agencies—railway, traction, highway, etc. in connection with legislation and public policy.

Obituary

Robert E. Chetwood, Plant Engineer of the Western Union Telegraph Company, died on Thursday, January 25, 1923. Mr. Chetwood who was born in Elizabeth, N. J., February 15, 1873 was a graduate in electrical engineering of Lehigh University, class of 1895. He immediately entered the Engineering Dept. of the A. T. & T. Co., specializing in the construction and maintenance of the outside plant. He left the A. T. & T. in 1910 to become Engineer of Construction for the Western Union Telegraph Co. Eventually be became Plant Engineer in charge of the engineering design of the entire plant including buildings and equipment. He held that position at the time of his death. Mr. Chetwood entered the A. I. E. E. as an Associate in 1903 and transferred to Member in 1912. He was a member of the Telegraphy and Telephony Committee from 1916 to 1921 then becoming Chairman for the year 1922-23. He was also a member of the Meetings and Papers Committee for 1922-23.

Addresses Wanted

A list of members whose mail has been returned by the Postal Authorities is given below, together with the addresses as they now appear on the Institute records. Any member knowing the present address of any of these members is requested to communicate with the Secretary at 33 West 39th Street.

1.—William R. Dwyer, 134 N. Lowell Ave., Syracuse, N. Y.
2.—Young-Tsieh Huang, c/o J. W. Dietz, Western Electric Co., 195 Broadway, New York, N. Y.
3.—Charles H. Hollenbeck, 7 Virginia Ave., W. Orange, N. J.
4.—J. M. Mercer, Bristol House, Holburn Viaduct, London, E. C., England.
5.—Robert W. Merritt, 845 So. Gramercy Place, Los Angeles, Calif.
6.—Thomas H. Parker, 1839 Tulare Street, Fresno, Calif.
7.—Geo. P. Portejoie, National Farming Mach. Ltd., Montmagny, P. Q., Can.
8.—J. M. Quinlan, 269 Beach Walk, Honolulu, T. H.

Past Section and Branch Meetings

PAST SECTION MEETINGS

Baltimore.—January 19, 1923. Subject: "Automatic Substations." Speaker: Mr. C. M. Davis. Attendance 56.

Boston.—January 9, 1923. Subject: "The Doble Method of Testing Insulators." Speaker: Mr. Frank C. Doble. Joint meeting with the Electrical Engineering Society of M. I. T. Attendance 150.

Chicago.—January 15, 1923. Subject: "Self-Starting Synchronous Motors as Applied to the Industry for Power Factor Correction and Industrial Installations." Speaker: Mr. S. H. Mortensen. Attendance 150.

February 5, 1923. Subject: "Antennae Design." Speaker: Mr. Frank Conrad, Asst. Chief Engineer of the Westinghouse Electric & Mfg. Co.

Cincinnati.—January 11, 1923. Subject: "Alternating-Current Generators." Speaker: Mr. R. B. Williamson, of the Allis-Chalmers Company. Attendance 71.

Cleveland.—January 23, 1923. Subject: "The Physical Nature of Speech and Hearing." Speaker: Dr. R. L. Jones, of the Western Electric Co. Attendance 300.

February 15, 1923.—A joint meeting of the Cleveland Section of the Institute and the Cleveland Chapter of the Illuminating Engineering Society was started at 7 p. m. on the evening of February 15, 1923 with a dinner to the 100 members of both societies present, as guests of the National Lamp Works. A paper was then presented by E. A. Anderson and O. F. Haas, Eng'g. Dept., National Lamp Works on the subject "Modern Street Lighting Plans for a Large City." The Membership Committee then reported 85 new applications, while quota was set at 60, Cleveland being first Section to reach its quota. The largest incandescent lamp in the country was then shown, rated at 30 kw., 120-volts, using approximately 40 horse power. A group photograph was taken by the light of the lamp mounted outside the window.

Connecticut.—January 30, 1923. Mr. Calvin W. Rice, Secretary of the A. S. M. E., gave a lecture on his recent trip to South America as a representative to the International Engineering Congress at Rio de Janiero. Attendance 85.

Denver.—January 26, 1923. Dr. Plumb spoke on radio communication, illustrating his talk with motion pictures loaned by the Western Electric Co. Attendance 60.

Detroit Ann-Arbor.—December 8, 1922. Subject: "The Social and Economic Significance of Engineering Developments in Simultaneous Telegraphy and Telephony." Speaker: Mr. R. D. Parker. Attendance 85.

January 10, 1923. Subject: "The Trend of Modern Motor Research." Speaker: Mr. E. B. Craft. Attendance 74.

Erie.—January 16, 1923. Subject: "History, Theory and Use of X-Ray." Speaker: Dr. E. G. Weibel. Attendance 90.

Fort Wayne.—January 18, 1923. Subject: "Magnetic Materials." Speaker: Mr. W. E. Ruder of the General Electric Co. Attendance 80.

Indianapolis-Lafayette.—January 25, 1923. Subject: "Obligations of the Public to the Utilities." Speaker: Hon. Edward N. Hurley. Attendance 500.

Ithaca.—January 18, 1923. Subject: "The Present Status of Railway Electrification." Speaker: N. W. Storer. Attendance 60.

Los Angeles.—December 19, 1922. Subject: "Rules of Overhead Line Construction." Speaker: Mr. J. E. McCaffrey. Attendance 54.

Lynn.—January 17, 1923. Subject: "Some Uncommon Aspects of Metallurgy." Speaker: Dr. F. S. Hoyt of the General Electric Co. Attendance 150.

Madison, Wis.—January 31, 1923. Subject: "Protective Relays and Continuity of Service." Speaker: Mr. L. N. Crichton of the Westinghouse Electric & Mfg. Co.

Milwaukee.—September 20, 1922. Subject: "The Design of the Largest Hydroelectric Power Plant in the World." Speaker: Mr. William M. White of the Allis-Chalmers Co. Attendance 250.

October 18, 1922. Subject: "Synchronous Motors for Power Factor Correction and Industrial Application." Speaker: Mr. S. H. Mortensen. Attendance 250.

November 22, 1922. Subject: "The Welded Infired Pressure Vessel as Used in the Refrigeration Industry." Speaker: Prof. R. J. Roark. Attendance 180.

December 20, 1922. Subject: "100-Ton-Miles per Gallon of Gasoline." Speaker: Mr. H. L. Horning. Attendance 340.

January 11, 1923. Subject: "Industrial Research." Speaker: Mr. E. B. Craft of the Western Electric Co. Attendance 600.

Minnesota.—January 10, 1923. Subject: "Some Aspects of Railway Electrification." Speaker: Mr. Ernest Marshall. Attendance 25.

Panama.—January 27, 1923. Subject: "The Wonders of the X-Ray." Speaker: Dr. Leroy S. Tonsend. Attendance 55.

Philadelphia.—January 8, 1923. Subject: "Wind Pressure Characteristics of Wires and Cylindrical Rods in Various Formations." Speaker: Mr. W. C. Wagner. Attendance 154.

February 12, 1923. Subject: "Recent Developments in Electrical Engineering with Particular Reference to Practise." Speaker: Mr. L. W. W. Morrow, of the *Electrical World*. Attendance 97.

Pittsfield.—December 21, 1922. Subject: "The Rewards of Labor." Speaker: Dr. Harry A. Garfield, President of Williams College. Attendance 100.

January 3, 1923. Lecture-Recital by Prof. Vladimir Karapetoff and Miss Viola M. Tuttle of Ithaca, N. Y. Attendance 350.

January 4, 1923. Subject: "Resonance and Oscillations." Speaker: Prof. Karapetoff of Cornell University. Attendance 150.

January 18, 1923. Subject: "The History and Development of the Falls for Power Purposes." Speaker: Mr. J. L. Harper. Attendance 300.

February 8, 1923. Subject: "Fundamental Considerations in the Design of Large Transformers." Speaker: Mr. F. F. Brand. Attendance 150.

Providence.—February 2, 1923. Subject: "Seeing but not Observing." Speaker: Mr. Wm. H. Blood, Jr., of Stone & Webster, Inc. Attendance 60.

Rochester.—January 26, 1923. Subject: "Storage Batteries." Speaker: Mr. J. H. Tracey, of the Electric Storage Battery Company. Attendance 50.

Seattle.—December 20, 1922. Subject: "Electric Heating." Speaker: Prof. Edgar Allan Loew, Associate Professor of Electrical Engineering, University of Washington. Attendance 35.

Schenectady.—January 5, 1923. Subject: "Resonance and Oscillations." Speaker: Prof. Vladimir Karapetoff, Professor of Electrical Engineering, Cornell University. Attendance 240.

January 19, 1923. Subject: "Arc Welding as Applied to Shipbuilding." Speaker: Mr. J. A. Seede. Attendance 160.

Springfield.—January 16, 1923. Subject: "The Engineers." Speaker: Mr. E. H. Sniffen, of the Westinghouse Electric & Mfg. Co. Attendance 75.

St. Louis.—January 24, 1923. Subject: "Radio Telephony." Speaker: Prof. R. S. Glasgow, of Washington University. Attendance 79.

Syracuse.—January 29, 1923. Subject: "Highway Lighting." Speaker: Mr. L. F. Heckman, of the Westinghouse Elec. & Mfg. Co. Attendance 50.

Toledo.—January 10, 1923. Subject: "Automatic Hydro-electric Stations." Speaker: Mr. R. J. Wensley, of the Westinghouse Elec. & Mfg. Co. Attendance 22.

Toronto.—January 12, 1923. Subject: "Industrial Heating by Electric Heat as Applied by Use of the Metallic Electric Resistor." Speaker: Mr. Otis, of the General Electric Co. Attendance 51.

Utah.—January 31, 1923. Subject: "Industrial and House Wiring." Speaker: Mr. F. D. Winegar. Attendance 86.

Vancouver.—January 5, 1923. Subject: "Radio." Speaker: Mr. R. M. Balfe, of the British Columbia Electric Railway Company.

Washington, D. C.—January 9, 1923. Subject: "American and European Practise on Large Generator Construction." Speaker: Mr. Frank D. Newbury. Attendance 173.

Worcester.—January 18, 1923. Subject: "The New England Power System—Economic Aspects, Financial Structure, Organization." Speaker: Mr. S. C. Moore, of the New England Power Company. Attendance 96.

PAST BRANCH MEETINGS

Alabama Polytechnic Institute.—January 13, 1923. There was a talk by Mr. W. W. Foster, a senior, on "Human Relations in Industry." and Mr. K. H. Stough gave a talk on "Getting Close to the Public." Attendance 21.

February 3, 1923. Subject: "Developments in Electrical Engineering During 1922." Speaker: Mr. P. S. Timberlake. Attendance 16.

University of Arkansas.—January 30, 1923. Business meeting. Attendance 15.

Bucknell University." January 24, 1923. An illustrated lecture "The Advantages and Opportunities of a Public Service Corporation" was given by Mr. O. R. Esbach of the Bell Telephone Co., the lecture being accompanied by the showing of slides. Attendance 41.

California Institute of Technology.—January 17, 1923. Subject: "High-Voltage Transformers" with special reference to a 1000-kv. transformer soon to be installed at this Institute. Attendance 30.

Carnegie Institute of Technology.—January 11, 1923. Subject: "Meters and Metering." Speaker: Mr. Thomas Pitzer of the West Penn Power Company. Attendance 85.

Case School of Applied Science.—January 12, 1923. Subject: "The Explanation of Various Radio Circuits." Attendance 50.

Clemson College.—February 8, 1923. Subject: "The Chippewa-Queenston Development." Part I—Hydraulic Development, by Mr. A. N. Shedley. Part II.—Generators, by Mr. J. H. Webb. Part III.—Arrangement for Handling 500,000-kw. Load, by Mr. D. B. Jones. General discussion of water power development was given by Prof. F. T. Dargan. Attendance 30.

University of Colorado.—January 17, 1923. A two-reel motion picture "The Audion" was shown by the courtesy of the Western Electric Company. There was an explanation by Mr. Russell H. Lindsay. Attendance 135.

University of Colorado.—January 29, 1923. There was a talk by Mr. H. T. Plum, one of the Vice-Presidents of the A. I. E. E., on "Education." Attendance 50.

February 7, 1923. Two student speakers gave talks on the Panama Canal and high-powered vacuum tubes. Attendance 20.

Cooper Union.—February 3, 1923. Subject: "TheTelephone Cable, Its Application and Use." Speaker: Mr. George B. Thomas. Attendance 50.

Drexel Institute.—December 11, 1922. Subject: "The Electro-Steam Boiler." Speaker: Mr. P. H. Falter. Attendance 28.

January 1, 1923. Subject: "Furnishing Telephone Service to a City Like Philadelphia." Speaker: Mr. J. R. MacGregor. Attendance 51.

Kansas State College.—January 15, 1923. Subject: "Sewage Disposal." Speaker: Mr. C. A. Howland. Attendance 65.

University of Kansas.—January 11, 1923. Subject: "The Northeast Power Station.—Kansas City, Mo." Speaker: Mr. F. S. Dewey. Attendance 44.

January 16, 1923. Illustrated lecture on "Control Systems," by Mr. E. F. Siphers, of the Westinghouse Electric & Mfg. Co. Attendance 60.

University of Kentucky.—January 25, 1923. Subject: "Power Development on the Mississippi River." Speaker: Mr. E. A. Bureau. Attendance 20.

Lafayette College.—December 16, 1922. Reviews and discussions taken from current engineering periodicals. Attendance 21.

January 9, 1923. Review and discussion of current periodicals by students. Attendance 20.

January 20, 1923. Review and discussion of current periodicals by students. Attendance 20.

Lewis Institute.—January 17, 1923. Business meeting. Attendance 14.

Marquette University.—January 18, 1923. Subject: "Vacuum Tubes and Their Applications." Speaker: Mr. Geo. Baumbach. Attendance 38.

School of Engineering, Milwaukee.—January 26, 1923. Subject: "Lamp Manufacturing." by Mr. F. G. Kaufman and "The Engineer and the Public", by Mr. J. A. Havlick. Attendance 27.

University of Minnesota.—January 24, 1923. Moving pictures and a short talk by Mr. O. E. Seiler, of the Phoenix Life Insurance Co. Attendance 61.

University of Missouri.—January 15, 1923. Subject: "The Romance of Electricity." Speaker: Prof. M. P. Weinbach. Attendance 45.

Montana State College.—January 16, 1923. There was an illustrated lecture by Mr. H. A. Houston of the Westinghouse Electric & Mfg. Co. on "Mechanical Equipment of Electric Locomotives." Attendance 141.

North Carolina College.—February 6, 1923. Subject "Radio Transmission." Speaker: Mr. C. W. Norman.

University of North Dakota.—January 15, 1923. There was a talk by Prof. D. R. Jenkins on "The Future of the Electrical Engineering Graduate" and a paper by Prof. Thomas Matthews on "Electric Utility Rates." Attendance 17.

Ohio Northern University.—January 25, 1923. An illustrated lecture was given by Mr. C. E. Weitz of the National Lamp Works, Cleveland, Ohio, on "Illumination." Attendance 35.

Ohio State University.—January 12, 1923. Presentation of the Joseph Sullivant Medal of the Ohio State University to Benjamin G. Lamme. Attendance 700.

January 26, 1923. Subject: "The Design of the Outside Telephone Plant." Speaker: Mr. E. F. Biggert. Attendance 150.

University of Oklahoma.—January 16, 1923. Illustrated lecture on rotary conductors was given by E. G. Reid. Attendance 24.

Oregon Agricultural College.—January 17, 1923. One reel picture "The Conductor" was shown by courtesy of the General Electric Co. Attendance 30.

University of Notre Dame.—January 22, 1923. Mr. John Scaron gave a report of an inspection trip to the hydroelectric power plant at Berrieu Springs, Mich. There was a paper by Mr. James I. Smith on "Automatic Substations." Attendance 21.

University of Southern California.—January 17, 1923. Subject: "The Design of High-Tension Protective Devices." Speaker: Mr. Lloyd Hunt. Attendance 17.

Oregon Agricultural College.—January 31, 1923. Business meeting. Attendance 37.

University of Pennsylvania.—October 13, 1922. Combined meeting of the Electrical, Mechanical and Civil Societies, at which time the heads of the departments addressed the students. Attendance 39.

November 8, 1923. Subject: "The Frankford Elevated." Speaker: Mr. Dodd. Attendance 45.

University of Pittsburgh.—January 5 1923. Prof. H. E. Dyche spoke on the advantages and purposes of the A. I. E. E. Attendance 34.

January 7 1923. Subjects: "The Theory and Uses of the Vacuum Tubes" by Mr. J. O. Kleber and "Calibration on Apparatus Loss in Terms of Standard Cable." Speaker: Mr. F. R. Gorman. Attendance 34.

January 19 1923. Subject: "What Constitutes a Man." Speaker: Mr. Wm. M. Bradshaw.

Purdue University.—January 23, 1923. Subject: "Economic Conditions of Today," by Mr. W. V. Owen, and "Electric Railway Problems" by Mr. C. R. Seybold. Attendance 45.

Rutgers College.—January 11, 1923. Three student papers were given: "Eight-Hour Day vs. Twelve-Hour Day," by Mr. K. C. Angleman, "Effect of Electrical Engineering on Industries," by Mr. Riley, and "The Chippewa Development," by Mr. Buck. Attendance 17.

Stanford University.—January 16, 1923. Social meeting. Attendance 35.

January 23, 1923. Business meeting. Attendance 28.

Swarthmore College.—January 12, 1923. There was an illustrated lecture on "The Story of Asbestos." Attendance 40.

January 19, 1923. Business meeting. Attendance 20.

February 2, 1923. Business meeting. Attendance 9.

February 9, 1923. Business meeting. Attendance 10.

University of Virginia.—January 11, 1923. Business meeting. Attendance 13.

January 18, 1923. Subject: "Distribution of Current for Light & Power," by Mr. R. B. Patterson, and "The Manufacture of Insulated Wires and Cables for Electrical Conductors and of Insulating Tapes." Lantern slides and moving pictures were shown. Attendance 39.

Virginia Polytechnic Institute.—January 22, 1923. Subject: "The G. E. Type of Electric Locomotive." Speaker: Mr. T. F. Cofer. Attendance 45.

University of Washington.—January 16, 1923. Subject: "Electric Locomotives." Speaker: Mr. V. H. Housten. Lantern slides illustrated the talk. Attendance 82.

University of Wisconsin.—January 10, 1923. Mr. Moon, of the Westinghouse Electric & Mfg. Co. gave a short talk on the accomplishments of the Westinghouse Corporation. Attendance 27.

Employment Service Bulletin

OPPORTUNITIES.—Desirable opportunities for service from responsible sources are announced in this Bulletin, and no charge therefor is made.

MEN AVAILABLE.—Under this heading brief announcements will be published without charge to the members. Announcements will not be repeated except upon request received after a period of three months, during which period names and records will remain in the active files.

NOTE.—Notices for the JOURNAL should be addressed ***EMPLOYMENT SERVICE, 33 West 39th Street, New York, N. Y.,*** *the employment clearing house of the National Societies of Civil, Mechanical, Mining and Electrical Engineers.*

Notices for the JOURNAL are not acknowledged by personal letter, but if received prior to the 16th of the month will appear in the issue of the following month.

All replies to either "Opportunities" or "Services Available" should be addressed to the key number indicated in each case and forwarded to ***EMPLOYMENT SERVICE,*** *as above.*

Replies received by the bureau after the position to which they refer has been filled will not be forwarded, and will be held by the bureau for one month only.

OPPORTUNITIES

ELECTRICAL MAINTENANCE MEN for work at mine and mill sites. Knowledge of Spanish and some technical training preferred. Application by letter. Salary not stated. Location, Chile. R-161.

STEAM PLANT SUPERINTENDENT. Want high grade technical graduate who has had direct experience in supervision and operation of public utility steam electric stations. Must have executive ability and be capable of handling men. Expect opening near future superintendent of power in charge of transmission system and plants for superintendent of steam station having 45,000 kw. installed. Location, center and southwest. Man experienced in handling up-to-date equipment and capable maintaining in equipment and economical operation desired. Application by letter giving full details, education and experience. State nationality, age, references and salary desired. R-170.

SALES MANAGER with radio experience to handle sales throughout United States and Canada. Experienced men only considered. Application in person. Salary not stated. Headquarters, N. Y. C. R-183. (An investment will be necessary.)

ELECTRICAL ENGINEERING GRADUATE with experience selling motors for sales work. Application by letter. Salary not stated. Location, Ohio. R-184.

DRAFTSMAN with street main and cable layout. Experience desirable. Application in person. Salary not stated. Location, N. Y. C. R-188.

ELECTRICAL DRAFTSMAN accustomed to layout and substation work, including transformers, oil switchboard, substation control, subway lighting. Two years' experience. Application in person. Location, N. Y. C. R-190.

ELECTRICAL ENGINEER for sales work to sell course for civil service school. Leads furnished. Evening work. Application by letter. Commission basis. Headquarters, New York City. R-199.

ASSISTANT ELECTRICAL FOREMAN. Preferably technical graduate 25-35 years of age. Several years of operating experience in modern power station, preferably with one of the large companies in the large cities. Westinghouse or G. E. test experience desirable but not necessary. Electric construction experience desirable but not necessary. Good personality. Ability to handle men. Application by letter. Salary not stated. Location, N. Y. C. R-202.

INSTRUCTOR in Electrical Engineering for September, 1923. Application by letter. Location, South. R-203.

ENGINEER of appearance and personality to work in statistical department. Must be good letterer. Application in person. N. Y. C. R-216.

RECENT E. E. graduate familiar with electric lighting circuits to work out lighting problem. Application in person. Location, N. J. R-218.

CONSTRUCTION ELECTRICAL ENGINEER. 4-5 years' experience since leaving school. Power plant construction and design along electrical engineering lines. Application by letter. Location, Tenn. & Carolina. R-220.

SALES ENGINEER to sell insulating varnishes and compounds. Middle western and eastern territory. Application by letter stating qualifications and experience. R-223.

MAN who has had experience in designing small simple machines that can be produced in quantity at low cost. We want a man who is thoroughly rounded in all mechanical principles and can apply these in the simplest and most direct way to get required results. The machine we want designed is a simple printing machine. Salary not stated. Application by letter. Location, New York. R-229.

YOUNG ELECTRICAL ENGINEER familiar with substation construction, calculations, drafting, etc. Application in person. Location, N. Y. C. R-246.

SALES ENGINEER who has contact with all the good builders, architects, engineers, industrial plants, etc., one who can procure business for us on the strength of his own name and reputation. Salary of such man would practically be without limit based entirely on his own efforts. Application by letter. Headquarters, New York City. R-254.

DRAFTSMAN familiar with car and locomotive construction and design. Application by letter. Location, West Virginia. R-255.

RECENT ELECTRICAL ENGINEERING GRADUATE to act as assistant to designer of fractional horse power motors. Application by letter. Salary not stated. Location, Ohio. R-256.

SEVERAL RECENT GRADUATE ELECTRICAL ENGINEERS to enter a public utility organization with intention of advancing to responsible positions in its various departments. Men are preferred who have had a year or two of experience such as a manufacturer's test course or experience with public utilities. These men would be started with statistical work in the general superintendent's office. Now need man to supervise private telephone line, a man for inspection work around high-tension apparatus and men for construction, engineering (civil, electrical and hydraulic), and in fact in almost every one of the departments of a power company. Application by letter. Location, New York State. R-257.

MANUFACTURERS REPRESENTATIVE who is an engineer and well acquainted with trade in New York City, to take over account of large, well established manufacturing plant, located in Eastern Pennsylvania. Must be capable of selling marine, mining, conveying, hoisting and special machinery also grey iron and bronze castings. Present sales gives an assured income but will expect considerable new business. Must have own office and work on commission basis. Application by letter. R-261.

INDUSTRIAL ENGINEER of broad experience in manufacture of woolen blankets or woolen cloth, and capable of analyzing the operating conditions of woolen mills, and making recommendations for improvements in their operating efficiency. Prefer man between 35-50 years of age. Application by letter. Salary not stated. Location not stated. R-267.

PRODUCTION MANAGER to take charge of plant manufacturing insulating varnish. Must have knowledge of dies of formulas for shellac composition and economical operation. Application by letter. Salary not stated. Location, N. Y. C. R-272.

AMBITIOUS YOUNG American Connecticut man preferred. Technical graduate, character, address and intelligence must rank high. Connection will develop into sales engineering work with established New England machinery distributor. No interview granted without detailed application. Salary not stated. Location, Conn. R-286.

SINGLE MAN for research work, in cement plant. Combustion experience essential. Application by letter stating age, education and experience. Location, Illinois. R-302.

DISTRICT MANAGER with sales experience not over 30 years old for company manufacturing induction motors and welders. Application by letter. Salary not stated. Location, Michigan. R-303.

TOOL DESIGNER preferably college graduate with mechanical experience. Must be able to handle work to an advantage and to design tools which will produce our class of work economically. The class of work which is made in this plant is 90 per cent brass and is practically instrument work made on an interchangeable basis. Application by letter. Salary not stated. Location, N. J. R-312.

FIRST-CLASS CHECKER for automotive equipment engineering dept. Should have good foundation in mathematics and machine design, together with 8-10 years' drawing room experience. It is preferable that about 5 years' of the drawing room experience be on starting, lighting and

ignition, although men with experience on small commercial electric motors, and generators manufactured on quantity basis, would be given consideration. Application by letter. Salary not stated. Location, Mass. R-313.

LICENSED RADIO OPERATOR with some electrical maintenance experience around a power house. Application by letter. Salary not stated. Location, Pa. R-317.

POWER PLANT DRAFTSMAN, qualified to make layouts of such equipment, including boilers, stokers, turbines, pumps and other power plant auxiliaries. Broad, thorough grasp of piping layouts is essential; electrical experience, while desirable, is not necessary. Work is under direction of power engineer and need not be technical graduate, though preference given to man with such training, if experience were satisfactory. Application by letter. Salary not stated. Location, N. J. R-331.

MAN with 5 or more years' teaching experience in Physics to take charge of department. Evening work only. 4 nights per week. Application by letter. Location, N. Y. C. R-333.

ENGINEER with broad knowledge of springs and thoroughly posted on steels, to analyze spring problems of truck manufacturers. Must have personal clientele in this line. Application by letter. Salary not stated. Location, Mass. R-347.

TECHNICAL GRADUATE who is not out of school more than 2 or 3 years, willing to go into research test department and work on development of induction motors. Such man will be offered an opportunity for advancement which will depend upon his abilities. Not absolutely necessary that man have induction motor experience but he must have a thorough technical education and some experience along manufacturing lines. Application by letter. Salary to start will be moderate. Location, Ohio. R-358.

ELECTRICAL ENGINEER with several years' experience on design, development and application of small or medium size industrial motors. Must be able to obtain independent results by analysis and experiment. Permanent position with old established company. Application by letter stating experience fully. Salary not stated. Location, Pennsylvania. R-368.

ELECTRICAL DISTRIBUTION ENGINEER to be responsible for design and inspection of distribution and transmission line construction, and for improvement in existing system in numerous medium sized towns principally in New York and Pennsylvania. Require first class man. Application by letter stating experience fully, salary desired. Location, N. Y. C. R-387.

INSTRUCTOR in Electrical Engineering for year Sept. 1923—June 1924 by leading university in Southwest. Duties will comprise class and laboratory work and possibly handling of some work in surveying and drawing. Recent graduate with some practical experience desired. Application by letter giving complete chronological account of training and experience with references. R-391.

ELECTRICAL DESIGNER. Recent graduate required for test department of large electrical public utility corporation. Work includes tests on electrical apparatus and machinery in various stations; on supplies, on cable systems; on customers' premises; and a widely diversified range for broad experience. Application by letter. Location not stated. R-429.

PHYSICAL LABORATORY requires the services of a technically trained young man. It is not necessary that he be experienced, but must be properly trained in carrying on physical laboratory tests, in making observations, and in recording data. Application by letter. Salary not stated. Location, New York. R-439.

DESIGNER for drafting on precise instrument work. Man out of college two years will be considered. Must be an American citizen Experienced men only considered. Application in person. Salary not stated. Location, N. Y. R-446.

EXECUTIVE with collapsable tube experience for finishing department. Only man with this experience considered. Application by letter. Location, N. J. R-447.

YOUNG MAN with sufficient drafting and designing experience to take charge of work of several detailers in connection with the designing of turbo-generators for headlights and farm lighting equipment. Position should lead to that of chief electrical or mechanical engineer within a year or so. Application by letter. Salary not stated. Location, Indiana. R-449.

YOUNG TECHNICAL GRADUATE IN ELECTRICAL ENGINEERING to take charge of the electrical laboratory of our engineering department. Work will consist of testing brushes on automobile equipment, small meters, slip rings and generators. Will be expected to work with research department in developing and testing new materials. Good opportunity for right man to develop into a brush engineer. One or two years' experience with small electrical machinery is desirable but not necessary. Application by letter. Salary not stated. Location, Penn. R-434.

AN ELECTRIC MANUFACTURING company needs men for test work in its laboratory. Work is largely on measuring instruments. Opportunities for experience and advancement are very good. The test positions can easily lead to development work for well qualified men. Men of some experience in the handling of test equipment are desired. Application by letter. Location, New England. R-451.

TRANSMISSION LINE DRAFTSMAN wanted by a large power company in Western Penna. Must be able to work up all field notes, use sage tables and charts and design structures for long spans. Prefer one who could qualify as squad chief. Application by letter. R-458.

MEN AVAILABLE

TECHNICAL GRADUATE, Nine years' experience as resident, plant and general electrical engineer. Desires position with established company ase stimator, contractor's follow-up man, installation road representative, or salesman along engineering lines in the metropolitan district. E-4154.

TECHNICAL GRADUATE, Electrical Engineering course, 1921, desires a sales or technical position in any capacity. Five years' of good practical electrical experience in designing, shop work and testing. At present engaged in La Salle business administration course. E-4155.

OPERATING SUPERINTENDENT, technical graduate, age 31, 10 years' experience, available for hydro and steam electric system; experienced in construction, operation, and maintenance of high-tension transmission lines both pole and steel tower, substations and central station apparatus. At present assistant operating superintendent on large system in Southeast. Desires change with wider responsibilities. Native American, married. E-4156.

YOUNG ENGINEER desires opportunity with hydroelectric company as an assistant to general manager or superintendent. M. I. T. graduate 1921, with some designing experience and some business experience. Desires permanent position. Age 23, unmarried. Best references. E-4157.

VALUATION ENGINEER. Electrical graduate of the University of Wisconsin. Ten years' experience: Three years on statistical, service, and valuation work with state commission; two years successful operation of combined gas, electric, and heating utility; and five years commercial valuation of utilities in executive capacity. Capable of taking complete charge of large valuations, special reports, and engineering investigations relating to public utilities. Age 35; married. Location desired depends on opportunity offered. E-4158.

MECHANICAL AND POWER ENGINEER. Technical graduate, B. S. and M. E. eight years broad experience in machine shop, sugar engineering, industrial and power plant practise, operation, design, layout, calculations, heat balance, utilization and distribution of steam, water, coal, power, etc., investigation, reports. Executive and business ability. E-4159.

INSTRUMENT ENGINEER. Have long experience in manufacture, development and sale in electrical measuring instruments. E. E. graduate, best of references. Would like position as engineer or in manufacturing. E-4160.

RADIO ENGINEER. B. S. degree; over ten years' personal experience in research and development work in radio; actual shop and plant experience; three years experience as special sales engineer for large manufacturing corporation; have been through the Alexander Hamilton business course; three foreign languages; capable of performing or directing performance of research or engineering development, especially with reference to receiving equipment. Will consider only high grade engineering or technical executive position. E-4161.

CHIEF ENGINEER OR CONSULTING ENGINEER. 23 years' experience in design and manufacture of all kinds of electric machinery. Many years' experience in handling men and in dealing with customers. Originator of systems for efficient cooperation of departments. Organizer of operation of departments. Organizer of engineering and testing departments of one of the largest manufacturing concerns. Designer of several lines of the best known polyphase and single-phase motors and generators. Pioneer in design and manufacture of automobile starters and generators. Numerous practical patents. Faculty member of large university. Author of many scientific papers. Fellow A. I. E. E. E-4162.

MECHANICAL ENGINEER. Technical graduate, B. S. M. E., Assoc. A. I. E. E., 4 years' experience power station and general construction as designer, inspector and valuation work, past eleven years on fire protection work, making surveys and preparing reports. Married. At present employed. E-4163.

MARINE ENGINEER (License as chief engineer for unlimited tonnage), with M. S. degree in electric engineering from Columbia University, also six years' practical experience at sea in marine and electrical engineering. Desires change. Opportunity for advancement and future is of primary importance. E-4164.

ELECTRICAL ENGINEER '22 and B. S. '21 desires a change of position. Has had 14 months' experience as a test man, development man and draughtsman. 9 months were spent at this work in radio. Would like to connect with a responsible firm in or near New York City. Starting salary $1800. E-4165.

INDUSTRIAL ELECTRICAL ENGINEER, Associate A. I. E. E. Technical education; married. Age 35.15 years' experience in industrial power generation, distribution and maintenance. Have also had charge of maintenance department of a large industrial concern, where I superintended the work of a staff of 40. Available at any time. E-4166.

VALUABLE MAN AVAILABLE. As president, general manager, works manager, consulting or supervising engineer. Excellent training for position with large general consulting engineering, bond, banking, trust or other financial corporation in investigation and reorganization work. Superior education and experience in public utility, mining, smelting, railroad, foundry, machine, metal piece part manufacture and other industries. Expert at organization, financing, administration

and economical operation and production. E-4167.

EXECUTIVE—SALES ENGINEER, successfully representing a New York City manufacturer in eastern city selling marine goods, desires to locate in New York. Wishes to represent as Branch or District Manager or Assistant, a manufacturer of electrical appliances, machine tools or sheet metal products. Familiar with factory production, electrical, radio and mechanical appliances and installations. Unquestioned proof of sales ability. E-4168.

TECHNICAL GRADUATE B. S. in Electrical Engineering. Age 34 desires position as designing and developing engineer. 18 months electrical testing 8 months transformer engineer. 12 years all around machinist and tool maker. Would also consider position as master-mechanic or assistant master-mechanic in an industrial plant. Salary depends on location. E-4169.

ELECTRICAL ENGINEER, Graduate, also college graduate. 5 years electrical and mechanical research and development, instrument standardization and expert pyrometric experience. Will consider position where previous experience is valuable or connection with corporation or consulting engineer desiring a young man willing to tackle any kind of engineering job. At present employed. Salary adjustable to locality and value of previous training. Age 30, married. E-4170.

ELECTRICAL ENGINEER, B. S. degree, age 32, single. Four years' practical experience along lines of light and power distribution and industrial installations and maintenance. For past three years has been assistant professor of mathematics and electrical engineering in New England. Now desires to make a change and to locate in the Southern States or in California. Would consider either teaching or industrial offer. Salary $3000. E-4171.

SUPERINTENDENT OR CHIEF-OPERATOR OF HYDRO PLANT, transmission and distribution system, wishes to make change. Technical and practical experience, competent to take entire charge of plant, construction, operation and maintenance. Married, age 41, references upon request. E-4172.

POWER ENGINEER desires work in central states, north or south. Now in charge of power system design, improvement, and operation for a New York consulting and management engineering firm specializing in industrial work in New England. Experienced in meeting, working with, and getting cooperation from all grades of men from operators to directors. Will be glad to refer you to present and past employers, in public utility and manufacturing work and to arrange for interview. E-4173.

ASSISTANT PROFESSORSHIP in ELECTRICAL ENGINEERING wanted by technical graduate of six years' experience in research and teaching. Member Sigma Xi. Degree M. E. Available Sept. 1, 1923. Minimum salary $2600. E-4174.

ELECTRICAL AND HYDRAULIC ENGINEER, technical graduate, age 37, married. 12 years' experience in engineering and operation high-voltage central station, water, and gas public utilities desires executive engineering or operation position where initiative, ability and industry will lead to advancement. At present employed. Salary partly contingent on location. Prefer middle Eastern states. E-4175.

CHIEF ELECTRICIAN, technical graduate, age 33, 10 years' experience on construction and maintenance of power plant, substation and industrial plant installations, desires a position with responsibilities and opportunities of advancement. E-4176.

YOUNG MAN, age 27, as assistant to executive, excellent technical education. 3 years with steamship auditing dept., and 7 years in maintenance department of large public utility. First class references. Employed, but available on short notice. E-4177.

ELECTRICIAN MAINTENANCE AND CONSTRUCTION FOREMAN. 12 years' experience on power switchboards. Automatic control, electric cranes, elevators, a-c. and d-c. motors, generators, etc., in large industrial plant. Good draftsman and tracer on large automatic motor control boards. At present employed. New York or New Jersey preferred. Minimum salary $2500. E-4178.

ELECTRICAL ENGINEER, technical graduate, member A. I. E. E., married, twenty years' experience, construction, maintenance and operation of hydro-electric and steam plants, a-c. and d-c., transmission lines 44,000-volt, distribution, public utility and electric railways. Several years manager and chief engineer for electric light and power companies, desires position as Manager, Superintendent or Electrical Engineer. Available on short notice. E-4179.

ELECTRICIAN, age 25 with eight years' experience in marine maintenance, substation, construction and repairs. Desires opportunity with advancement. E-4180.

ENGINEER at present on installation work in Nevada, desires position in the West. Age 39. Married. 17 years' experience on isolated plant design, installation and construction in towns, mills and mines, and department stores. Industrial applications of electric motive power a specialty. Correspondence solicited. E-4181.

INSTRUCTORSHIP, M. I. T. Graduate, 1922, desires to enter teaching as a profession. Has had some teaching experience. At present employed in engineering work. Would like to teach Heat Engineering or some Electrical Engineering subject, with chance to study for higher degree, available on short notice. E-4182.

SALESMAN or responsible position in Sales or Credit Dept., of Manufacturer of electrical products. Young married man, age 29, four years' similar experience in concern manufacturing electrical power apparatus. Now employed but present employers contemplate retiring. Experience covers selling, credit, collections, estimates, quotation, preparation of sales literature, and handling correspondence. Can direct others. Present location near New York City. Northeastern U. S. desired but can go anywhere. E-4183.

DISTRIBUTION ENGINEER, technical graduate with five years' experience. Desires permanent connection with opportunity, preferably as assistant to engineer or superintendent with fair-sized property. At present employed as superintendent of small utility. Age 26, married, Scandinavian. Location immaterial if good opportunity is at hand. Available in about four weeks. Good references as to ability and character. E-4184.

ELECTRICAL ENGINEER: Technical graduate, with additional training in railroad work. Eight years' experience on electrical design and supervision of construction on large industrial layouts and power plants. Desires opportunity for permanent position with an electric railway, public utility, or consulting engineer. E-4185.

SUPT. of SUBSTATION OR ASSISTANT TO SUPT. OF DISTRIBUTION desires similar position west of Chicago. Technical graduate. Five years in operation, maintenance and construction of substations. Two years in the engineering dept. Two years steam and gasoline engine experience. Available on two weeks notice. Age 32. Married. E-4186.

ELECTRICAL ENGINEERING STUDENT in 4th year of a night course, 5 years' mechanical drafting experience, desires position with electrical concern in New York City. Available on one weeks' notice. E-4187.

ELECTRICAL ENGINEER desires position with consulting engineer or public utility corporation. Thoroughly experienced in design of generating and transformer stations including switchboards, connection diagrams, reinforced concrete structures, conduit etc. Also telephone and signal systems. Age 32, married. Available 30 days. E-4188.

ENGINEER, available after June 1, 1923. Practical man. Fifteen years' experience in power house and substation operation, maintenance, and construction. At present employed in Hawaiian Islands but desire change. Would prefer location in South America. Anything reasonable considered. E-4189.

DISTRIBUTION ENGINEER, age 33, technical education, 13 years' experience, 8 years of which has been in distribution work with large central stations, desires a change. Has made a study of distribution economics, and is familiar with the best practise. Location preferred, West or Northwest. E-4190.

SALES ENGINEER. Graduate Electrical Engineer; age 34; aggressive; live wire. 8 years' experience selling building and electrical supplies to dealers and jobbers. Has large following among architects, builders and engineers in New York and Long Island. Highest references supplied upon interview, and will supply car to cover territory. E-4191.

ENGINEER for testing, development or design work on electrical or mechanical apparatus. Technical graduate. Four years of experience in testing and development of electro-mechanical apparatus with large engineering concern. Experienced with physical properties of metals and insulation materials. 26 years of age. Head of family. Desire permanent connection. E-4192.

ELECTRICAL ENGINEER, 1923 graduate of large Eastern University, desires position with power company or electric manufacturing company in the middle west or California. Four years' practical experience. Age 26, married. Available July 1st. E-4193.

ELECTRICAL ENGINEER graduating in May 1923 from Case School of Applied Science, Cleveland, Ohio, desires an opportunity in the manufacturing field or in power house construction and design. Also very much interested in illumination having received a one year course given by the Nela Park organization. E-4194.

ELECTRICAL ENGINEER, technical graduate, G. E. Test, 10 years superintendent of utility, handling transmission, distribution and sale of electric light and power and gas, desires change to straight engineering in either central station property or industrial plant. Age 36, married. Experienced in supply and utilization of large power. E-4195.

RESEARCH ASSISTANT. Graduate in Physics and Engineering. Desires position affording opportunity for research as applied to engineering. Some experience in pure research. At present graduate student. Age 22. Member American Physical Soc. E-4196.

WIRE CHIEF, at liberty in April; seventeen years experience in the electrical business, eight years of which has been purely telephone work. Specialize in Western Electric telephone equipment, both common battery and magneto. Location abroad, preferably in a Spanish speaking country. Age 33, married, present salary $3600. E-4197.

ELECTRICAL ENGINEER: Cornell graduate, middle-aged, ten years experience as E. E. on large steam road; five years as Superintendent of public utility plants; five years in Government service on railroad valuation, and three years experience in appraisal work of public utilities; married; excellent health. Location immaterial; available on short notice; would like to connect with a going concern. E-4198.

MEMBERSHIP—Applications, Elections, Transfers, Etc.

ASSOCIATES ELECTED FEBRUARY 15, 1923

*ALFERY, HENRY FRANK, Erecting Engineer, Allis Chalmers Mfg. Co., Milwaukee, Wis.

*ALLEN, C. EDWARD, Asst. Power Apparatus Engineer, Western Electric Co., 84 Marion St., Seattle, Wash.

ALLEN, DAVID E., Cadet Engineer, Syracuse Lighting Co., Syracuse, N. Y.

*ALLEN, LAWRENCE HERMAN, Engineer, Western Electric Co., Inc., 463 West St., New York, N. Y.; res., East Orange, N. J.

ALLEN, WALTER R., Sales Engineer, General Electric Co., 1301 Pierce Bldg., St. Louis, Mo.

*ANDERSON, JOHN WHITE, 3rd, Design Calculator, Philadelphia Electric Co., 1000 Chestnut St., Philadelphia, Pa.: res., Camden, N. J.

*ANGEL, HARRY HERMAN, Motor Control Engineer, Maryland Plant, Bethlehem Steel Co., 513 D St., Sparrows Point, Md.

BABER, JAMES EARL, Electrical Engineer, Galesburg Railway, Light & Power Co., Galesburg, Ill.

BALLARD, JOHN ADAMS, Capt., Signal Corps, U. S. Army, Asst. Prof. of Military Science, University of Wisconsin, Madison, Wis.

BALTZER, JOHN BERTRAM, Instrument Maintenance, United Railways Co., 3869 Park Ave., St. Louis, Mo.

BANGS, HAROLD HOYT, Asst. Manager, Home Electric Co., Hendersonville, N. C.

*BAXTER, RALPH HERMAN, Field Engineer, Southwestern Bell Tel. Co., 354 Boatmens Bank Bldg., St. Louis, Mo.

*BENTLEY, ALBERT NELSON, Service & Meter Man, San Joaquin Light & Power Corp., San Joaquin, Calif.

BERGH, FREDRIK GEORG, Messrs. Electromotor, S. A., Apartado 480, Mexico D. F., Mex.

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CARSWELL, ROBERT McCLEAN, Capt., Coast Artillery Corps., U. S. A. Army; Mass. Inst. of Technology, Cambridge; res., Brookline, Mass.

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SLOCUM, CHESTER C., Long Lines Engineering Dept., American Tel. & Tel. Co., 195 Broadway, New York, N. Y.; res., Westfield, N. J.
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SMITH, THOMAS DUNN, Central Office Engineer, Western Electric Co., 3541 Flournoy St., Chicago, Ill.
SMITH, WALTER, Asst. Superintendent, Washington Coast Utilities, Wentachee, Wash.
SMITH, WALTER LEWIS, Junior Electrical Engineer, Dept. of Public Service, Bureau of Power & Light, City of Los Angeles, 207 S. Broadway, Los Angeles, Calif.
*SNIDER, HOWARD N., Junior Test Engineer, Industrial Controller Co., 886 Greenbush St., Milwaukee, Wis.
SOMERVILLE, THOMAS DONALD, Testing Dept., Westinghouse Electric & Mfg. Co., E. Pittsburgh; res., Turtle Creek, Pa.
*SORENSON, HELMER, Line Estimator, The Milwaukee Electric Railway & Light Co., Public Service Bldg., Milwaukee; res., Whitefish Bay, Wis.
*STAMPER, HAMILTON ALAN, Inspector of Maintenance, Operation & Equipment, Public Service Commission, 49 Lafayette St., New York; res., Brooklyn, N. Y.
*STATHAS, PERICLES P., Senior, College of Engineering, Marquette University, 602 State St., Milwaukee, Wis.
STEWART, CHARLES CLEMENCE, General Traffic Supervisor, Canadian National Telegraphs, 40 Richmond St., W., Toronto, Ont.
*STROM, ALBERT PAUL, Instructor, Electrical Engineering Dept., Purdue University, W. Lafayette, Ind.
*STUMPF, WALTER, Chief Engineer, The Black & Decker Mfg. Co., Towson Heights; res., Towson, Md.
SULLY, ROBERT BRYANT, Testing Dept., General Electric Co., Schenectady, N. Y.
SUMMERS, GUY MELVIN, General Repair Man, North East Service, Inc., 391 Lyell Ave., Rochester, N. Y.
SVITAVSKY, ROBERT L., Electrical Engineer, The Milwaukee Electric Railway & Light Co., Milwaukee, Wis.
SYMES, ALFRED N., Fundamental Plan Engineer, The Ohio Bell Telephone Co., 4300 Euclid Ave., Cleveland, Ohio.
SYMONDS, CLARENCE MORTON, Substation Operator, Potomac Electric Power Co., Washington, D. C.; res., Arlington, Va.
*TENNEY, HARRY WILLIS, M. & P. Engineering Dept., Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., Wilkinsburg, Pa.
*TERMAN, FREDERICK E., Student, Mass. Institute of Technology, 426 Newbury St., Boston, Mass.
*THOMAS, ALBERT GALLATIN, Student, Mass. Institute of Technology, Cambridge, Mass; res., Lynchburg, Va.
*THOMPSON, ELMER OLAF, Dept. of Development & Research, American Tel. & Tel. Co., 195 Broadway, New York, N. Y.
TILLOTSON, NOYES D., Switchboard Designing Dept., General Electric Co., Schenectady, N. Y.
*TURNER, EDMUND THOMAS, Supt. of Construction, North American Illuminating & Engineering Co., 778 Rogers Ave., Brooklyn, N. Y.
TYLER, CHARLES LEE, Chief Electrician, Wentz Co., Markle Bank Bldg., Hazleton, Pa.
UHL, FREDERICK, Division Traffic Supt., American Tel. & Tel. Co., 4300 Euclid Ave., Cleveland, Ohio.
UNDERHILL, JOHN V., Mechanical Draftsman, Nassau Light & Power Company, Glenwood, L. I., N. Y.
VANDEVORT, JOHN HALBERT, Supervisor of Electricity, Fortification Division, Panama Canal, Balboa, C. Z.
VAN HOOK, ERRETT, Engineer, Georgia Railway & Power Co., 454 Electric & Gas Bldg., Atlanta, Ga.
VEVERKA, FRANK, Foreman, Electrical Construction, United Hudson Electric Corp., 751 Elton Ave., New York, N. Y.
VOIGT, EDWARD ALBERT, Inspector, Brooklyn Edison Co., 569 Fulton St., Brooklyn; res., Richmond Hill, N. Y.
*WALKER, CEDRIC JOSEPH, Electrical Construction, The New England Power Co., 35 Harvard St., Worcester, Mass; Brattleboro, Vt.
WATERS, BARRETT, President, Kentucky Power Co., Brooksville, Ky. and 307 1st National Bank Bldg., Cincinnati, Ohio.
WEINGARTNER, CHARLES R., Electrical Engineer, General Electric Co., Witherspoon Bldg., Philadelphia, Pa.
WENTY, OLIVER HENRY, In Charge of Electrical Design, Power Drafting Dept., Bureau of Power & Light, City of Los Angeles, 207 S. Broadway, Los Angeles, Calif.
WHISLER, GEORGE M., Resident Electrical Engineer, Westinghouse High Voltage Insulator Co., Derry, Pa.
WILDER, ROBERT FARNSWORTH, Supt. of Distribution, The Twin State Gas & Elec. Co., Dover, N. H.
*WILLIAMS, ARTHUR LIONEL, Junior Electrical Engineer, Bureau of Power & Light, City of Los Angeles, 207 So. Broadway, Los Angeles, Calif.
WILSON, ARCHIBALD F., Supervisor of Plant Operations, The Ohio Bell Telephone Co., 4300 Euclid Ave., Cleveland, Ohio.
WILT, MELVIN C., Engineering Dept., National Lamp Works of General Electric Co., Nela Park, Cleveland, Ohio.
WISNER, RAYMOND REX, Electrical Engineer, Stone & Webster, Inc., 147 Milk St. Boston, Mass.
*WOLLAM, GERALD ZENUS, Student, University of California, Berkeley, Calif.
WOODMANSEE, WALTER L., Head Electrician, American Steel & Wire Co., South Works, 767 Milbury St., Worcester, Mass.
WOODS, ARTHUR JAMES, Construction Engineer, General Electric Co., 84 State St., Boston, Mass.
*WYCHE, PHILIP LUDWELL, Mechanical Draughtsman, Denver Tramway Co., Denver, Colo.
YOUNG, PHILIP C., Erecting Engineer, Service Dept., Canadian Westinghouse Co., Hamilton, Ont., Can.
*YOUNG, W. FORREST, Engineer, Duquesne Light Co., 435 Sixth Ave., Pittsburgh, Pa.
ZAHM, JOSEPH JOHN, Draftsman, Dept. of Docks, New York City, Pier "A," North River, New York; res., Brooklyn, N. Y.

Total 244.

*Formerly Enrolled Students.

ASSOCIATES REELECTED FEBRUARY 15, 1923

BIRDSALL, WILFRED THOMAS, Consulting Engineer, 41 N. Fullerton Ave., Montclair, N. J.
BROWN, HARRY FARNSWORTH, Asst. Electrical Engineer, N. Y. N. H. & H. R. R., 323 Railroad Station, New Haven, Conn.
HOLLAND, MAURICE, Chief, Industrial Engineering Branch, McCook Field, Dayton, Ohio.

JOHNSON, ALEXANDER LAUGHLIN, Asst. Electrical Engineer, West Penn Power Co., 14 Wood St., Pittsburgh, Pa.

KELLEY, WALTER F., Engineering Dept., Western Electric Co., New York, N. Y.

MILLER, CLAYTON A., Engineering Dept., Adirondack Power & Light Corp., Schenectady, N. Y.

SHEPHERD, GEORGE, Electrician, Durant Motors of Canada Ltd., Leaside; res., Toronto, Ont., Can.

WEEKS, HAROLD EASTMAN, Capt., Air Service, Officers Reserve Corps., Army & Navy Club, Washington, D. C.

MEMBERS ELECTED FEBRUARY 15, 1923

CHAPIN, CARL KENNETH, Bureau of Power & Light, Dept. of Public Service, City of Los Angeles, 207 So. Broadway, Los Angeles; res., Pasadena, Calif.

CRAPO, CHARLES AMBROSE, Engineer of Equipment & Buildings, Mountain States Tel. & Tel. Co., Denver, Colo.

DEERING, JOHN JOSEPH, Manager, Norton Office, West Virginia Engineering Co., Norton, Va.

DICKEY, ROBERT WILLIAM, Associate, Professor of Electrical Engineering, Washington & Lee University, Lexington, Va.

FLETCHER, HARVEY, Dept. Head, Transmission Research, Western Electric Co., 463 West St., New York, N. Y.

HIBBARD, LLOYD JAMES, Railway Equipment Engineer, Engineering Dept., Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.

KING, ROBERT WALDO, Electrical Engineer, American Tel. & Tel. Co., 195 Broadway, New York, N. Y.

LYNG, JOHN JOSEPH, Apparatus Development Engineer, Western Electric Co., 463 West St., New York, N. Y.

MAXFIELD, JOSEPH PEASE, Development Engineer, Western Electric Co., 463 West St., New York, N. Y.; res., Maplewood, N. J.

OBERLANDER, FELIX REID, Electrical Engineer, Garfield Smelting Co., Garfield; res., Salt Lake City, Utah.

PORTNELL, JAMES ROY, Superintendent, Electrical Distribution, Union Electric Light & Power Co. 315 N. 12th St., St., Louis, Mo.

TOENSFELDT, RALF THOMAS, Electrical Engineer, Dept. of Public Utilities, City of St. Louis, 311 City Hall, St. Louis, Mo.

WILLIAMSON, BERT ALFRED, Electrolysis Engineer, Los Angeles Gas & Electric Corp., Los Angeles, Calif.

TRANSFERRED TO GRADE OF FELLOW FEBRUARY 15, 1923

PECK, BERT H., General Manager, Southern Illinois Light & Power Co., St. Louis, Mo.

TRANSFERRED TO GRADE OF MEMBER FEBRUARY 15, 1923

BERN, EMIL G., Switchboard Engineer, General Electric Co., Schenectady, N. Y.

BOWDITCH, ROY, Electrical Engineer, West Virginia Engineering Co., Norton, Va.

MURNAN, J. A., Electrical Superintendent, Motive Power Dept., Interborough Rapid Transit Co., New York, N. Y.

WOLF, H. CARL, Chief Engineer, Public Service Commission of Maryland, Baltimore, Md.

RECOMMENDED FOR TRANSFER

The Board of Examiners, at its meetings held January 15 and February 9, 1923, recommended the following members of the Institute for transfer to the grades of membership indicated. Any objection to these transfers should be filed at once with the Secretary.

To Grade of Fellow

KEBLER, LEONARD, President, Ward Leonard Electric Co., Mt. Vernon, N. Y.

To Grade of Member

AFFEL, HERMAN A., Engineer, Dept. of Development and Research, American Telephone & Telegraph Co., New York, N. Y.

BROWN, R. A., General Superintendent, City Electric Light & Street Railway Departments, Calgary, Alberta, Canada.

CLAYTOR, EDWARD M., Electrical Engineer, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

DEANS, WILLIAM, Chief Engineer, Sundh Electric Co., Newark, N. J.

JOHNSON, ARTHUR F., Chief Electrical Draftsman, Brooklyn Edison Co., Brooklyn, N. Y.

MAYER, GEORGE H., Supt. Telegraph, Minneapolis, St. Paul & Sault Ste. Marie R. R. Co., Stevens Point, Wis.

NOTVEST, G. ROBERT, Electrical Engineer & Manufacturers' Agent, Cleveland, O.

ROWLAND, HERBERT R., Chief Engineer, Moody Engineering Co. Inc., Secretary, Moody Construction Co., Inc., New York, N. Y.

SCHEALER, SAMUEL R., Associate Professor of Electrical Engineering, Lehigh University, Bethlehem, Pa.

SPOONER, THOMAS, Research Engineer, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

WATTS, EGBERT M., Patent Work (Temporarily), Canadian General Electric Co., Toronto, Ont.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute, the list indicating the geographical district and Section in which the applicant is at present located. Unless otherwise indicated, the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before March 31, 1923.

Adams, Ira J., New York, N. Y.
Aird, Alanson W., Port Jefferson, N. Y.
Arkinson, Thomas J., New York, N. Y.
Armstrong, Thomas W., Johnstown, Pa.
Ashley, David P., New York, N. Y.
Avendano, Julio, New York, N. Y.
Banister, William C., Milwaukee, Wis.
Bank, Martin L., Chicago, Ill.
Barron, Donald W., New York, N. Y.
Barton, Fred B., Montreal, Que
Bass, Alexander H., Philadelphia, Pa.
Bass, Percy B., Newark, N. J.
Baum, Edwin K., Stanford University, Calif.
Begoon, George F., New York, N. Y.
Belknap, J. Harrison, Corvallis, Ore.
Bell, Emerson DeW., New York, N. Y.
Benz, Bernhard, Portland, Ore.
Berejkoff, Anatol P., Schenectady, N. Y.
Bergman, Earl, Youngstown, Ohio.
Best, Gerald Martin, San Francisco, Calif
Beverage, Harold H., Belmar, N. J.
Bissiri, Alfio, Los Angeles, Calif.
Black, John C., Bentonville, Ark.
Blain, James G., Cleveland, Ohio.
Blodget, Hugh Y., Deadwood, S. Dakota.
Bonney, Alva A., Portland, Ore.
Briggs, Elmer C., Cleveland, Ohio.
Broach, Keator T., New York, N. Y.
Brooks, Guy W., Buffalo, N. Y.
Brown, Melvin P., New York, N. Y.
Browning, Kenneth W., Salt Lake City, Utah.
Buckheit, William, New York, N. Y.
Buckley, Harry G., Jr., Brooklyn, N. Y.
Bullen, Charles V., Stillwater, Okla.
Burgett, James E., Warwood, W. Va.
Burkholder, John C., Jr., New York, N. Y.
Cadwallader, Asa G., Columbus, Ohio.
Capen, William H., (Member), New York, N. Y.
Carlson, George E., (Member), Chicago, Ill.
Carroll, G. Rees, Woodlawn, Pa.
Case, Everett W., Pittsburgh, Pa.
Chatham, Francis M., Jr., Salisbury, Md.
Chesebro, Milton E., Spokane, Wash.
Chittick, William A., Milwaukee, Wis.
Clark, Orson B., Pittsburgh, Pa.
Clarke, DaCosta M., Philadelphia, Pa.
Clarke, Edith, Schenectady, N. Y.
Clement, Lewis M., (Member), New York, N. Y.
Cole, Clarence S., (Member), Jamestown, N. Y.
Cole, Howard W., Allentown, Pa.
Collette, Reginald C., New York, N. Y.
Comiskey, Walter V., New York, N. Y.
Connery, Alder F., New York, N. Y.
Conrad, Frank L., (Member), Chicago, Ill.
Cooper, Alfred M., Kansas City, Mo.
Cosmenky, G. Francis, New York, N. Y.
Cox, Francis A., New York, N. Y.
Cureton, Francis H., New York, N. Y.
Dean, Charles E., New York, N. Y.
Dean, Charles S., Boston, Mass.
Detlor, William K., Kingston, Ont.
Dixon, Walter C., (Member), E. Pittsburgh, Pa.
Donahue, John C., Boston, Mass.
Dreher, Carl, New York, N. Y.
Dreyer, John F., Jr., Hoboken, N. J.
Dummel, Robert G., San Francisco, Calif.
Dunn, Charles P., (Member), Portland, Ore.
Dyke, Minor B., Akron, Ohio.
Eaton, Earle, Detroit, Mich.
Ege, William W., Chicago, Ill.
Ellis, William G., Philadelphia, Pa.
Everist, Thomas B., Philadelphia, Pa.
Eyre, James R., (Member), Iowa City, Iowa.
Falknor, Frank B., E. Pittsburgh, Pa.
Farnsworth, Arthur J., (Member), Los Angeles, Calif.
Feather, Robert J. B., Columbus, Ohio.
Fell, Robert A., E. Pittsburgh, Pa.
Fey, Charles F., Long Island City, N. Y.
Fitch, James H., Cleveland, Ohio.
Fitzgerald, John, W. Lynn, Mass.
Flye, William L., New York, N. Y.
Fox, Arthur W., (Member), Hartford, Conn.
Garrison, Dwight, Philadelphia, Pa.
Gerringer, Harold LeR., Reading, Pa.
Glendening, William R., Nelsonville, Ohio.
Gloslie, Christian, Dawson, Y. T.
Graham, Tom, Salisbury, Md.
Graham, Rhodes T., Porterville, Calif.
Granau, Edgar L., Woonsocket, R. I.
Griffiths, Clarence M., New York, N. Y.
Guenther, Felix G. H., Madison, Wis.
Gustafson, Edgar H., Cleveland, Ohio.
Hagen, Roy C., Butte, Mont.
Halpern, Henry H., New York, N. Y.
Hamilton, Hance L., Columbus, Ohio.
Hamilton, Harold C., Boston, Mass.
Hammond, Herbert H., Boston, Mass.
Hand, Ellsworth J., Washington, D. C
Hannum, Dane M., New York, N. Y.
Hansell, Clarence W., New York, N. Y.
Harter, Leslie J., Cleveland, Ohio.
Haug, Andrew J., Seattle, Wash.
Heistad, Rolf, Los Angeles, Calif.
Herzog, Eugene, New York, N. Y.
Hill, Arthur P., Los Angeles, Calif.
Hillegass, J. B., Erie, Pa.
Hillier, Clifford G., Boston, Mass.
Hobbs, George V., Baltimore, Md.
Hobson, C. C., Portland, Ore.
Hodge, William E., Lynn, Mass.
Hoffman, Samuel O., San Francisco, Calif.
Hohn, Charles L., Cleveland, Ohio.
Holman, John A., Cleveland, Ohio.
Hoover, William J., (Member), Ft. William, Ont.
Hopson, William H., Portland, Ore.
Hubbard, Francis A., (Member), New York, N. Y.
Hull, Burt G., (Fellow), Detroit, Mich.
Humrickhouse, Ralph R., Cleveland, Ohio.
Huntington, Ernest K., Rochester, N. Y.
Hurd, Howard H., Cleveland, Ohio
Huston, Claude B., Schenectady, N. Y.
Hutcheson, James P., Cleveland, Ohio.
Irvine, C. Nes, Zanesville, Ohio.
Jenkins, Paul S., (Member), Detroit, Mich.
Jeynes, Paul H., Ansonia, Conn.
Johansen, Theodore R., New York, N. Y.

Johnston, Jack F., Portland, Ore.
Jones, Leland, Grace, Idaho.
Jufer, Walter, Schenectady, N. Y.
Kaiser, Alexander A., Philadelphia, Pa.
Keller, Joseph M., Erie, Pa.
Kempson, James M., Schenectady, N. Y.
Kent, Harold D., New York, N. Y.
Kerr, Clarence L., Schenectady, N. Y.
Ketcham, E. D., Albany, N. Y.
King, Elmer D., Detroit, Mich.
Kinney, Clair Y., Detroit, Mich.
Kinzie, P. Alexander, Denver, Colo.
Kishpaugh, Arthur W., New York, N. Y.
Knight, Montgomery, Cambridge, Mass.
Knowles, Arthur W., Worcester, Mass.
Kuhn, Clarence W., Cincinnati, Ohio.
Lang, Harold C., Clarksburg, W. Va.
Leach, Dallas A., Cleveland, Ohio.
Leavell, George H., Salem, Ore.
Leconte, Robert A., New York, N. Y.
Lenz, Andrew H., Cleveland, Ohio.
Loving, Orville O., Powell, Wyoming.
Lund, Carl E., E. Orange, N. J.
MacLeod, Hector J., Edmonton, Alta., Canada.
Magnuson, John E., Duluth, Minn.
Marquis, Vernon M., Schenectady, N. Y.
Marshall, Walter W., W. Allis, Wis.
Mathes, Charles E., Toledo, Ohio.
Mattson, Walter A., W. Lynn, Mass.
McKay, Herbert, St. Catharines, Ont.
McMichael, Frank G., Pittsburgh, Pa.
McNeill, Clarence E., Philadelphia, Pa.
McNerney, Adelbert M., Cleveland, Ohio.
Mechling, Eugene B., Philadelphia, Pa.
Meslo, Clarence E., Detroit, Mich.
Mitchell, Clair D., Bloomfield, N. J.
Montgomery, John A., Columbus, Ohio.
Moody, Harry L., Philadelphia, Pa.
Moore, Charles E., Jr., Baltimore, Md.
Morgan, Kenneth F., Pasadena, Calif.
Morse, William O., Schenectady, N. Y.
Moulton, Bruce S., Jackson, Mich.
Muehlig, Ralph E., Boston, Mass.
Murphy, Matthew F., Portland, Ore.
Murray, Frederick J., New York, N. Y.
Myers, Warren K., Huntingdon, Pa.
Neuber, Otto, Toledo, Ohio.
Noertker, Joseph A., Cincinnati, Ohio.
O'Brien, Laurence A., Jersey City, N. J.
Olmsted, Irl L., Portland, Ore.
Orr, Robert C., Jr., New York, N. Y.
Ostrom, Cyrus W., Seattle, Wash.
Peacock, Thomas E., Clarkdale, Ariz.
Pennell, Robert O., New York, N. Y.
Pfaultz, Christian E., Riverhead, L. I., N. Y.
Phillips, Frank D., Schenectady, N. Y.
Pierce, Glen K., (Member), Iowa City, Iowa.
Powell, Carroll A., New Haven, Conn.
Prossor, Donald K., New York, N. Y.
Quigley, William J., Bay Shore, N. Y.
Radel, L., Cleveland, Ohio.
Rawling, Arthur, (Member), E. Pittsburgh, Pa.
Read, Ben. S., (Member), Denver, Colo.
Reed, Thomas C., Cincinnati, Ohio.
Reardon, Kenneth N., Boston, Mass
Rey, Walter J., Milwaukee, Wis.
Rice, Harry J., Jersey City, N. J.
Rienstra, Petrus J., (Member), New York, N. Y.
Riley, James R., New York, N. Y.
Roever, Frank H., Cincinnati, Ohio.
Roloff, Delbert F., Ft. Wayne, Ind
Rooks, Alfred W., Flint, Mich.
Rossrucker, Edgar A., Cleveland, Ohio.
Rowe, Norman O., Schenectady, N. Y.
Rudolph, Paul C., Ft. Wayne, Ind.
Russell, Howard C., Cleveland, Ohio.
Sampson, Elmer B., Chatham, Mass.
Sarnoff, David, (Member), New York, N. Y.
Schott, John T., New York, N. Y.
Schultz, Otto H., Jr., Atlanta, Ga.
Schulze, Raymond P., San Francisco, Calif.
Scott, Hoyt S., Cleveland, Ohio.
Seely, Kenneth B., Boston, Mass.
Sharman, Frank H., New York, N. Y.
Shaw, Ralph M., Jr., Fresno, Calif.
Shreve, Charles T., Trenton, N. J.
Shutow, Tokuchiyo, New York, N. Y.
Smith, Everett H., New York, N. Y.
Smith, Frank S., Cleveland, Ohio.
Smith, Harry S., Pittsfield, Mass.
Sorenson, Charles N., Clarinda, Iowa.
Spofford, Franklin D., New York, N. Y.
Sterne, William C., Denver, Colo.
Stewart, Ronald B., San Francisco, Calif.
Stocksdale, Theodore R., (Member), Newark, N. J.
Stokes, Benj. B., Jr., Atlanta, Ga.
Stormzand, Harold A., Detroit, Mich.
Strauss, Jacob S., New York, N. Y.
Strong, Lewis B., Brooklyn, N. Y.
Struss, Frederick C. C., Franklin, N. H.
Stuart, Robert B., Mare Island, Calif.
Summers, Edwin S., Warwood, Wheeling, W. Va.
Teich, Quintin C., Ft. Wayne, Ind.
Tesch, Walter L., Port Jefferson, N. Y.
Thomas, Harry M., Oakland, Calif.
Thorburn, James M., Cleveland, Ohio.
Tischer, Herman A., Cincinnati, Ohio
Truran, Walter W., New York, N. Y.
Turnpaugh, Walter S., (Member), Monterrey, N. L., Mex.
Tuttle, Howell A., Toronto, Ont.
Tuttle, Willis H., Los Angeles, Calif.
Utt, Orville G., Cleveland, Ohio.
Vaile, Horace S., Chicago, Ill.
Varney, Herbert V., Toledo, Ohio.
Venning, F. J., Keokuk, Iowa.
Victoreen, John A., Cleveland, Ohio.
Vogel, Frederick M., W. Lynn, Mass.
Wade, Elmer J., Pittsfield, Mass.
Wager, Lewis B., Holtwood, Pa.
Walsh, Joseph F., New York, N. Y.
Walton, Edwin F., Portland, Ore.
Watson, Leroy F., San Francisco, Calif.
Wilson, Ray H., Tulsa, Okla.
Wilder, Laurence R., (Member), New York, N. Y.
Wiles, Glenn E., E. Pittsburgh, Pa.
Wilson, Carl H., Detroit, Mich.
Winkley, Erastis E., (Member), Lynn, Mass.
Witthun, William C., Montreal, Que.
Wolfson, Henry M., New York, N. Y.
Wood, Harry G., (Member), New York, N. Y.
Woodhead, John W., Vancouver, B. C.
Woodward, Guy F., Worcester, Mass.
Yelton, Paul H., Riverside, Calif.
Young, J. Harold, New York, N. Y.
Young, Louis H., Elk River, Idaho.
Ziegler, Edward F., Brooklyn, N. Y.
Total 211.

Foreign

Akasaka, Toshi, Shibuya, Tokyo, Japan.
Badhnivalla, J. N., Stretford, Manchester, Eng.
Christianson, Theodore C., Trafford Park, Manchester, Eng.
Curry, Aubrey R., Chuquicamata, Chile, S. A.
Geerling, William E., Johannesburg, S. Africa.
Hatton, Frank, Santo Domingo City, Santo Domingo.
Henry, Edward, Christchurch, N. Z.
Hutton, Leslie B., Hamilton, N. Z.
Ito, Taneharu, Shinagawa, Tokyo, Japan.
Mejia, J. Federico, San Salvador, Rep. of Salvador
Mellonie, Stanley R., Trafford Park, Manchester, Eng.
Stout, Carroll O., Fortaleza (Ceara), Brazil, S. A.
Total 9.

STUDENTS ENROLLED FEBRUARY

16467 Oberle, Nicholas, Montana State College
16468 Whipkey, C. E., Ohio Northern University
16469 Kukde, S. P., Ohio Northern University
16470 Charleton, Eugene E., Stevens Institute of Technology
16471 Corbett, William R., Jr., Stevens Institute of Technology
16472 Rufwold, Arnold S., University of Wisconsin
16473 Tuites, Clarence E., Clarkson College of Technology
16474 McIlhenny, I. F., Mass. Institute of Tech.
16475 Houk, John T., Yale University
16476 Griffith, Fuller O., A. & M. College of Texas
16477 Weaver, Alfred B., A. & M. College of Texas
16478 Hoefle, Alois, State College of Washington
16479 Findley, Russel L., University of Missouri
16480 Foltz, Joseph P., University of Missouri
16481 Linney, Ralph W., University of Missouri
16482 Herrington, Harold W., University of Kansas
16483 Price, Myron H., University of Kansas
16484 Baker, Ackland J., Queens University
16485 Stevens, Thomas A., Northeastern Univ.
16486 Neumann, Adelbert G., University of Wis.
16487 Hopler, Elliott S., Bucknell University
16488 Slepian, Arthur, Harvard University
16489 Jadot, Albert, Cornell University
16490 Shiroyan, Haig, Cornell University
16491 Sunico, Francisco, Cornell University
16492 Hayes, Ewan R., Mass. Institute of Tech.
16493 Drazen, A. Michael, Mass. Institute of Technology
16494 Gilley, Thomas G., A. & M. College of Texas
16495 Behar, Angelo, Mass. Institute of Tech.
16496 Morrison, Raymond D., Worcester Polytechnic Institute
16497 Todd, Edward E., Jr., Alabama Polytechnic Institute
16498 Stevenson, Adlai R., Alabama Polytechnic Institute
16499 Stevenson, Joe W., Alabama Polytechnic Institute
16500 Heath, William P., Alabama Polytechnic Institute
16501 Turner, Warren C., Alabama Polytechnic Institute
16502 Miller, Henry K., Alabama Polytechnic Institute
16503 Hays, Arthur C., Alabama Polytechnic Institute
16504 Gamble, Cary B., Alabama Polytechnic Institute
16505 Bevis, James F., Alabama Polytechnic Institute
16506 Ambrose, Julian M., School of Engineering of Milwaukee
16507 Nelson, Earl E., School of Engineering of Milwaukee
16508 Strom, W., School of Engineering of Milwaukee
16509 Bartell, Elmer, School of Engineering of Milwaukee
16510 Kress, Fred C., School of Engineering of Milwaukee
16511 Foulk, Richard K., School of Engineering of Milwaukee
16512 Posada, Ernest, School of Engineering of Milwaukee
16513 Gallup, W. Godron, School of Engineering of Milwaukee
16514 Moore, Sidney A., School of Engineering of Milwaukee
16515 Freshwater, Edison C., School of Engineering of Milwaukee
16516 Nazario, Antonio J., School of Engineering of Milwaukee
16517 Flowers, Samuel, School of Engineering of Milwaukee
16518 Stearns, Adlow A., School of Engineering of Milwaukee
16519 Losie, Willis E., University of Michigan
16520 Wilcox, Harry L., University of Michigan
16521 Lucas, Clarence E., University of Michigan
16522 Hoefflin, Albert S., University of Michigan
16523 Mooney, Robert H., University of Michigan
16524 Morton, Henry J., University of Michigan
16525 Duerr, Karl B., University of Michigan
16526 Thielman, Joseph A., University of Del.
16527 Schaeffer, George T., Keystone Institute
16528 Trollinger, George C., Keystone Institute
16529 Breininger, Leonard J., Keystone Institute
16530 Grimes, Joseph Peter, Keystone Institute
16531 Mussleman, Paul A., Keystone Institute
16532 Harper, Paul D., Keystone Institute
16533 Baisch, Harold F., Keystone Institute
16534 Clifford, Paul R., Keystone Institute
16535 Ley, Harry S., Keystone Institute
16536 Reber, Harry E., Keystone Institute
16537 Clausen, Elmer W., University of Minn.
16538 Pulver, Richard F., University of Minn.

16539 Kulor, John J., Central Technical School
16540 McRoberts, Joseph A., Central Technical School (Toronto)
16541 Belfrey, Ralph S., Central Technical School (Toronto)
16542 Wetton, Norman H., Central Technical School (Toronto)
16543 Thompson, Roy, Central Technical School (Toronto)
16544 Terry, Alexander, University of Colorado
16545 Ralston, Albert A., University of Illinois
16546 Kubiak, Henry J., Drexel Institute
16547 Hopper, Richard H., Oregon State Agricultural College
16548 Kietzmann, Edward H., University of Wisconsin
16549 Holton, Theodore R., Worcester Polytechnic Institute
16550 Fenner, Lawrence G., California Institute of Technology
16551 Krupy, Alexander J., Mass. Institute of Technology
16552 Whitby, Lewis S., Pennsylvania State Coll.
16553 Middleton, Walter C., Alabama Polytechnic Institute
16554 Hunt, Orville D., State College of Wash.
16555 O'Neil, Horace T., State College of Wash.
16556 Maughmer, Glenn F., State College of Washington
16557 Lundquist, Robert E., State College of Washington
16558 Schultz, Stanley M., University of Maine
16559 Cawvey, Clarence E., University of Illinois
16560 Voris, Henry L. J., University of Illinois
16561 Oliver, Rudolph S., Jr., Georgia School of Technology
16562 Quallins, George A., Georgia School of Technology
16563 Moore, Lauriston G., Jr., Georgia School of Technology
16564 McGee, Herbert S., Georgia School of Technology
16565 Johnson, Marion, Georgia School of Tech.
16566 Cox, Burns C., Georgia School of Tech.
16567 Blakey, Lawrence M., Georgia School of Technology
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16570 Paden, Ralph P., University of Colorado
16571 Campiglia, Eugene J., University of Colorado
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16573 Greene, Harry A., Jr., Stanford University
16574 Stray, George R., Stanford University
16575 Shepherd, Theodor H., Stanford University
16576 Johnson, Richard E., Stanford University
16577 Sortor, Charles H., Stanford University
16578 Lane, John C., Stanford University
16579 Young, Wilmer W., Stanford University
16580 De Vault, Aylett F., Stanford University
16581 Bush, Loren S., Stanford University
17582 John, Harold T., Stanford University
16583 Sandretto, Paul J. B., Stanford University
16584 Meyer, Charles L., Stanford University
16585 Trummer, David J., Stanford University
16586 Peavy, Claude E., Stanford University
16587 Smith, Lemuel C., Jr., Stanford University
16588 Putcamp, William J., Stanford University
16589 Lee, William G., Jr., Stanford University
16590 Swanson, Oscar J., Carnegie Institute of Technology
16591 Long, Le Roy W., Pennsylvania State Coll.
16592 Hays, Lloyd D., Marquette University
16593 Benton, Andrew, Marquette University
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16595 Butterworth, Percy T., Northeastern Univ.
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16598 Ceulbourn, Edward R., University of Alabama
16599 Martz, Clyde J., University of Alabama
16600 Hagler, Clyde E., University of Alabama
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16602 Graham, William F., University of Ala.
16603 Weston, Carl A., University of Alabama
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16606 West, Harold R., University of Utah
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16616 Erickson, Edward H., Purdue University
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16654 Devlin, James J., Keystone Institute
16655 Shollenberger, Howard A., Keystone Inst.
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16695 Schroeder, Frank W., Lewis Institute
16696 McAllister, Louis W., Lewis Institute
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16740 Wilson, Robert E., Oregon Institute of Technology
16741 Clark, Raymond F., Northeastern Univ.
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16747 Stratton, Julius A., Mass. Institute of Technology
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16749 Gustafson, Orien A., University of Idaho
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16751 Weseley, Milford D., Armour Inst. of Tech.
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16753 Andrews, Sidney, Mass. Institute of Tech.
16754 Fishman, Abraham, Drexel Institute
16755 Austin, Richard H., Jr., Washington Univ.
16756 Charlton, O. E., Mass. Inst. Tech.
16757 Geiker, J. Alfred, Drexel Institute
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16760 Rietz, Earl, Rensselaer Polytechnic Inst.
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16762 Roach, Francis D., Rensselaer Polytechnic Institute
16763 Palmer, John H., Rensselaer Polytechnic Institute
16764 Drake, Walter M., Rensselaer Polytechnic Institute
16765 O'Neil, Charles A., Rensselaer Polytechnic Institute
16766 Siniapkin, Nikolai M., Rensselaer Polytechnic Institute
16767 Taylor, Alfred L., Rennselaer Polytechnic Institute
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16769 Davidson, Joseph, Rensselaer Polytechnic Institute
16770 Waugh, John E., Rensselaer Polytechnic Institute
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16772 Tuite, Edgar J., Rensselaer Polytechnic Institute
16773 Colligan, Arthur L., Rensselaer Polytechnic Institute
16774 Hollerau, John T., Rensselaer Polytechnic Institute
16775 Goldenson, Moses A., Rensselaer Polytechnic Institute
16776 Scheel, Elwyn, Kansas State Agricultural College
16777 Clements, Verne O., Kansas State Agricultural College
16778 Gilbert, Merton L., Northeastern Univ.
16779 Giersch, Otto L., University of North Caro.
16780 Dellinger, Everette E., University of North Carolina
16781 Shepard, Thomas H., Jr., University of North Carolina
16782 Ross, Harold L., University of North Caro.
16783 Harding, William K., University of North Carolina
16784 Smith, Charles F., University of North Carolina
16785 Seyffert, George F.,Jr., University of North Carolina
16786 Pruitt, Basil A., Clemson A. & M. College
16787 Shealy, Alexander N., Clemson A. & M. College
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16789 Pugh, Robert W., Clemson A. & M. College
16790 Anderson, Edward J.,Jr., Clemson A. & M. College
16791 Dean, Francis F., Clemson A. & M. College
16792 Dukes, William A., Jr., Clemson A. & M. College
16793 Brown, Alva B., Montana State College
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16795 Nesbet, Clarence K., Ohio Northern Univ.
16796 Strahan, Henry C., Cornell University
16797 D'Italia, Raymond, Northeastern Univ.
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16799 Meinig, Alfred R., Oregon Agricultural College
16800 Haylor, Herterl C., University of Utah
16801 Russell, Earl E., Oregon Agricultural Coll.
16802 Aldrup, Earl W., Oregon Agricultural Coll.
16803 Dean, Frank C., Oregon Agricultural Coll.
16804 Miller, Herman N., Oregon Agricultural College
16805 Miller, Horace N., Oregon State Agricultural College
16806 Starr, Eugene C., Oregon Agricultural College
16807 Dilley, Harold W., Oregon Agricultural College
16808 Gore, Daniel J., Georgia School of Tech.
16809 Patterson, Karl M., Georgia School of Technology
16810 Terrill, Stuart F., Brown University
16811 Stewart, Archie V., Pennsylvania State College
16812 Akins, Stuart W., University of Colorado
16813 Connelly, Louis A., University of Colorado
16814 Callow, Charles A., University of Colorado
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16816 Randall, John C., University of Colorado
16817 Cuenin, Fred. D., University of Colorado
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(A list of the personnel of Institute committees may be found in the January issue of the Journal. Will be reprinted in the June Journal.)

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(The Institute is represented on the following bodies; the names of the representatives may be found in the January issue of the Journal and will be published again in the June issue.)

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A. I. E. E. SECTIONS AND BRANCHES

A list of the 47 Sections and 68 Branches of A. I. E. E., with the names of their officers, may be found in the January issue of the Journal.

DIGEST OF CURRENT INDUSTRIAL NEWS

NEW CATALOGUES AND OTHER PUBLICATIONS

Mailed to interested readers by issuing companies.

Coal Hoisting Equipment.—Bulletin 4, 12 pp. Describes the coal unloading, storage and hoisting plant at the Hell Gate Station of the United Electric Light & Power Company. The Maine Electric Co., Portland, Maine.

Copper Clad Steel Wire for Radio Use.—Folder. Describes the application of "Copperweld" in radio installations for antenna, lead-in and ground wire, and ground rods. Also contains the Underwriters' rules for receiving stations, 1922 revision. Copper Clad Steel Co., Rankin, Penna.

Radio Instruments.—Bulletins recently published on electrical and radio laboratory apparatus are contained in a binder distributed by the General Radio Company, Cambridge (39) Mass. Among the equipment described are Variable Air Condensers, Vernier Condensers, Standard Condensers, Decade Condensers, Variometers, Standards of Inductance, Standards of Resistance, Decade Resistance Boxes, Wavemeters, Decade Bridges, Capacity Bridges, Slide Wire Bridges, Audibility Meters, Hot Wire Meters, Galvanometers, Thermo-Couples, Telephone Transformers, Ratio Arm Boxes, Audio Oscillators, Power Amplifiers, Amplifier Units and miscellaneous apparatus.

NOTES OF THE INDUSTRY

Hall Bros. Cedar Company, have moved their general office from Jacksonville, Texas, to Coeur d' Alene, Idaho, and will engage in the manufacture and wholesaling of Western Red Cedar Poles, Posts and Piling.

Large Volume of Steam Turbine Business for Westinghouse.—In the last few months orders have been received for steam turbine generators aggregating nearly 600,000 kw. by the Westinghouse Electric & Manufacturing Company, East Pittsburgh. These machines have been purchased by the leading central stations and large industrial plants located all over the country. Included in these orders is the largest turbine ever built by the company, a 62,500 kv-a. generator for the Brooklyn Edison Company, and the machine with the highest steam pressure, 500 lbs., 50,000 kw., for the Commonwealth Edison Company. Commenting on this large amount of business, Mr. E. H. Sniffin, Manager, Power Sales Department of the Westinghouse Company, stated that the amount of steam turbine business which will be done this year will only be limited by the manufacturing capacity. Production during the coming year will be very large. Sections of the plant in which these large machines are built have been working at full capacity since last summer. Previous to that time, there was a dearth of new business covering an eighteen-month period. This condition brings out the ever-recurring fact that steam turbines are purchased when the money market is easy and finances can be obtained to build new plants and add new equipment to existing stations. At other times central stations must give the best possible service with equipment available, irrespective of demand. This condition shows an unsatisfactory situation, especially in the face of the fact that the increase in the demand for energy is fairly constant and can be predicted. When the central stations can more uniformly carry on their required construction the electrical industry will be on a sounder basis.

The Gibb Instrument Company, Bay City, Mich., maker of electric welding equipment, has increased its authorized capital stock from $75,000 to $175,000. Of the increase $40,000 has been sold at par to provide increased manufacturing facilities and to take care of a rapidly increasing business.

High-Heat Mica Plate.—The New England Mica Company, Waltham, Mass., has perfected a process for the manufacture of built-up mica, which has been placed on the market under the trade name of Y-26 High-Heat Mica Plate. It is claimed for the new product that not only are the insulating properties of natural mica retained, but that it can be produced in large quantities in sheets of any thickness to sell at a very low price.

Associated Spring Corporation, New York.—Announcement is made of the incorporation, under the laws of the State of New York, of the Associated Spring Corporation, in which the following concerns unite: The Wallace Barnes Company, Bristol, Conn., The Wm. D. Gibson Company, Chicago, Ill., Raymond Manufacturing Company, Corry, Penna., Barnes-Gibson-Raymond, Inc., Detroit, Mich., The Wallace Barnes Company, Ltd., Hamilton, Ont.

Loud Speaker.—To meet the demand for a moderately-priced loud speaker, the Bristol Company, Waterbury, Conn., has placed on the market a new loud speaker horn, under the trade name "Audiophone Jr.," which is used for radio receiving. It is equally satisfactory for both instrumental and vocal music, also speeches, announcements, etc. In addition to radio reception this loud speaker is used to amplify phonograph records of all kinds. Another important application of the loud speaker is for call-systems in large offices, for paging in hotels, etc. No separate storage battery for magnetizing current is required. In order to make the horn suitable for all types of radio amplifier circuits, a transformer is mounted in the base.

New Savings Plan for Employees.—Securities of a number of important public utility companies are made part of an interesting new savings plan for General Electric Company employees through the formation of the G. E. Employees Securities Corporation, details of which have been made public by President Gerard Swope. A particularly interesting feature is that employees will themselves have a voice in the Securities Corporation by virtue of electing seven bond directors. The G. E. Company chooses eight directors representing the stock of corporation. Outlining the plan, President Swope, the in a formal announcement, said in part:

"In the past three years many thousands of our employees have, in addition to the purchase of about 50,000 shares of the company's capital stock, subscribed for over $5,000,000 of Employees 7 Per Cent Investment Bonds. This gratifying result has led the Board of Directors to adopt a broader plan, enabling employees to continue and extend the habits of saving thus formed.

"With the thought in mind that the employees might wish to become interested not only in the General Electric but also in the securities of the public utilities which the General Electric Company serves, a new company, the G. E. Employees Securities Corporation, has been formed to invest its funds in the stock of the General Electric Company and in the securities of public utility companies. The G. E. Employees Securities Corporation will issue: $5,000,000 of 6 per cent fifty-year bonds; and $10,000,000 shares of no par value capital stock. The General Electric Company will subscribe for the entire issues of bonds and stock. The stock will be retained by the General Electric Company, but the bonds will be sold to employees."

The bonds will be registered and issued in multiples of $10. Payments may be made by deductions from wages in one year. The maximum amount for which any employee may subscribe is $500 per year. An attractive feature is that the General Electric Company agrees with the original holder of bonds that so long as he remains in the service of the Company, it will pay at the same time the interest is paid, an additional 2% per annum, making a total of 8% per annum in the value thereof. The company has issued detailed regulations governing the holding of these securities.